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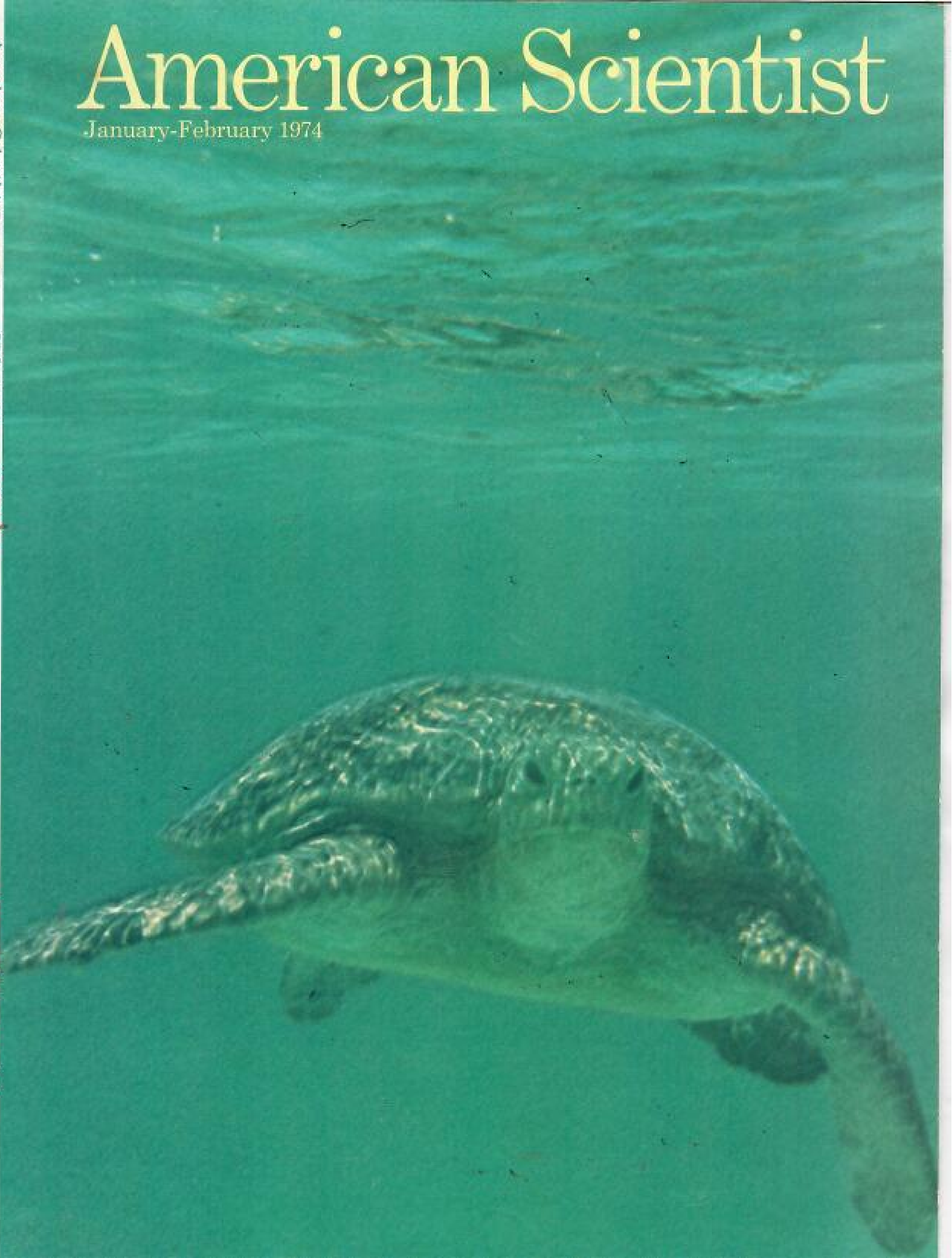

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Conserving the Edible Sea Turtle: Can Mariculture Help?

Commercial husbandry does not necessarily protect endangered species

Wild animal farming and ranching have frequently and increasingly been suggested as means of protecting species endangered by commercial demand. This concept, posing a critical issue for wildlife managers, ecologists, and conservation planners, is often accepted uncritically as a matter of proven fact rather than conjecture. Nevertheless, specific evaluation of the impact of wild animal farming on populations of endangered animals is seldom encountered in the literature. What is needed is a series of case studies to describe the specific biological and economic conditions that determine whether the farming of wild animals will have a positive or negative influence on the conservation of a given species and eventually to provide a basis for generalization. This paper presents such a case study—namely the effect of commercial mariculture on the conservation of sea turtles.

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This article is adapted from a paper presented to the Section of Biological and Medical Sciences, New York Academy of Sciences, which met on 12 March 1973 to discuss the topic "Food from the Sea." The author acknowledges the helpful criticism of Archie Carr and Richard Tennant in the preparation of this paper. *Address: Barnard College, Columbia University, New York, NY 10027.*

Chelonia mydas, known to different maritime peoples by a variety of common names including "green turtle," "*tortuga blanca,*" "edible turtle," and "soup turtle," has been described as "the most valuable reptile in the world" (*1*). The commercial products obtained from green turtles include leather, calipee (dried belly cartilage for soup), eggs, meat, and sometimes shell. From a nutritional standpoint the most important of these products is meat: a single adult turtle may contain 100 pounds or more of edible, tasty muscle.

The adult green turtle is largely herbivorous. It feeds on marine algae and shallow-water pastures of *Thalassia, Zostera,* and similar marine grasses that occur throughout tropical oceans; this plus its historically documented potential to achieve huge populations constitute the great value of this reptile to man. As Randall (*2*) has pointed out, the green turtle in the Caribbean (and presumably elsewhere) is the only large, edible vertebrate to graze the tropical marine pastures, the manatee being mostly restricted in its distribution to rivers, estuaries, and coastal lagoon systems. Moreover, unlike many other marine herbivores, the green turtle rarely eats things that make its flesh toxic to man.

Nutritional data for the green turtle are scanty but probably adequate; they have been reviewed and summarized by Hirth (*3*). In brief, the turtle is about 40 percent edible meat, which in turn is 80 percent water (like the meat of fishes), about 15 percent protein, and less than one percent fat. Nietschmann (*4*), who studied a Miskito Indian village in Nicaragua, calculated that two medium-sized green turtles per day could satisfy the meat requirements of the 997 people in the village at their average rate of consumption of animal protein—"assuming a theoretically even distribution of meat." For these Indians, the protein yield for turtling is 20 percent higher than for hunting (peccary, deer): "Therefore, even though the Tasbapauni Miskito are on the edge of a vast tropical forest environment [and even though the Miskito prefer the fatty meat of the peccary to that of the turtle], more than 65% of the active adult men concentrate their meat-getting efforts only on turtling."

Green turtle meat is clearly an excellent source of animal protein derived from vegetable matter. To put it differently, the most obvious significance of the green turtle in our time is that it occupies the second trophic level in an increasingly hungry world, utilizing an otherwise nearly unexploited habitat in the biosphere and thus not competing directly or indirectly with man for food. Furthermore, it is known to be capable of existing in large numbers near what are now the most densely populated and protein-hungry portions of the inhabited earth.

Conservation and mariculture

The problems of green turtle conservation and mariculture cannot be understood without some prior knowledge of the natural history of the species. Despite the taxonomic differences that undoubtedly occur in this rather poorly described group of animals, there is a worldwide pattern to their habits: they often feed in one place and nest in another, these two places being separated by distances as great as 1,400 miles (*5*). It is believed that under natural conditions green turtles nest only at the beach where they were born, making the round-trip journey between feeding and nesting grounds every two, three, or four years during what are probably long reproductive lifetimes. This leads to the genetic isolation of populations whose members may share feeding grounds with turtles from other breeding grounds; for example, some of the green turtles that feed near the coast of Brazil breed and nest at Ascension Island, others breed and nest at beaches in Surinam.

Hatchling green turtles seem to be carnivorous for the first few months of life (*6*). They probably eat marine invertebrates while being carried passively by the currents from their birthplace to their prospective adult feeding grounds. Toward the end of the first year of life, at the feeding grounds, or at some intermediate spot, they become primarily herbivorous, but the transition is never complete: green turtles always retain a fondness or preference for animal food in captivity, and adults in the wild, according to Bustard (*7*), will supplement their vegetable diets with "any animal food they can catch," especially jellyfish. The turtles take approximately 5 to 7 years to mature; their weight at maturity varies from 200 to about 400 to 500 pounds (91 to about 182 to 227 kg), depending on the individual and the population. Growth is exceedingly slow (about 2.5mm/year) after reproductive maturity is reached (*8*).

There is no way of knowing the sizes of green turtle populations in the past; however, all evidence indicates that within recent history there were at least two to three orders of magnitude more turtles than exist now, and possibly even more. According to Parsons (*9*), Audubon told of a man in the Dry Tortugas who single-handedly harpooned 800 green turtles in a month. This was in the nineteenth century, toward the end of the period of green turtle abundance. In 1630, Pieter Ita, also quoted by Parsons, described a single nesting beach on Little Cayman Island where one or two thousand turtles could be taken each night.

Ingle and Smith (*10*), in turn quoting from Everman in 1896, state that in 1886 a Mr. Charles Parke caught 2,500 turtles in the Indian River region of Florida, using eight nets. By 1890, only four years later but after more than a decade of intensive fishing there, it took 24 men using 168 nets to catch 738 turtles. Despite the decline in the Florida turtle fishery in the 1890s, in 1897 fishermen all over the state still reported a total catch of 634,616 pounds, mostly green turtles: this would equal about 3,000 adult animals.

Today, only the occasional stray green turtle can be found in the waters around the Cayman Islands, the Dry Tortugas, or the mouth of the Indian River; nesting in these places, even by a single individual, is a newsworthy event. At former nesting and feeding grounds in other parts of the world the same pattern is found: from Aldabra to Mexico to Sarawak, green turtle populations are a tiny fraction of their former size.

In the 1600s there were numerous nesting grounds, many with populations of tens or hundreds of thousands of nesting turtles. Now I estimate that the total world population of what we call *Chelonia mydas*, a group including several subspecies and possibly several distinct species of sea turtles, numbers between 100,000 and 400,000 adult males and females, with the waters of the China Sea, the Gulf of Aden, and the east coast of Australia sheltering some of the largest remaining populations (*11*). Despite the decline of the green turtle, commercial exploitation, buoyed by the development of demand for turtle oil (for cosmetics) and leather and by the introduction of new, highly portable meat-processing technologies, has increased its pressure on the surviving populations.

It was inevitable, given the vulnerable circumstances of highly localized feeding and nesting, that mariculture be suggested as a rapid means of conserving green turtles; and now, in fact, green turtle mariculture exists on a large commercial scale (*12*) and must be evaluated. The conservation arguments usually advanced by the proponents of mariculture are as follows: (1) Mariculture will drive the turtle fishermen out of business by offering the buyers of turtle products better, more uniform goods in large quantity and at an assured rate of supply. (2) Mariculture provides a source of extra animal protein for human consumption. (3) Mariculture can compensate for its current dependence upon and removal of eggs from natural nesting beaches by releasing a small number of subadult turtles nurtured past the dangerous period of hatchling mortality; moreover, by protecting the hatchlings from predators and thereby increasing their survivorship at least 50-fold, mariculture can take advantage of a huge and otherwise wasted fraction of the population. (4) Mariculture's research on the raising and breeding of green turtles in captivity will be useful to governmental and private conservation organizations and will ultimately lead to the development of procedures for maintaining an active breeding stock, which will render mariculture independent of wild populations. Problems with these claims will be considered in detail in the following paragraphs.

Ecological problems

First, there are the strictly ecological problems related to feeding in captivity. It does not seem practicable in a commercial operation to enclose enough underwater grasslands to maintain, for a long period of time, tens of thousands of subadult green turtles without substantial supplementary feeding. Furthermore, this type of pasturage is not likely to provide much food for large numbers of carnivorous hatchlings. The only rational alternative for a commercial operation is holding all turtles in small pens (or tanks on land) and supplying 100 percent of the food. This is the marine equivalent of feedlot agriculture, with some of the undesirable ecological side effects that have been described for its terrestrial equivalent by Commoner (*13*).

Figure 1. "Escort" males approach a mated pair of green turtles *(Chelonia mydas)* in the waters of Australia's Great Barrier Reef. The complex underwater behavior of this species has only recently been described and photographed; much of its life history, including the role of escort males, remains obscure. (Photograph courtesy of Julie Booth.)

The excrement of the massed turtles, instead of recycling nutrients over a large grazing area, becomes a local pollution problem. The crowding of the turtles in pens increases the hazard of disease: two common problems are respiratory infections and the infection of skin lesions (caused by the biting that occurs among crowded green turtles) by several types of marine bacteria. Such infections may be prevented or controlled, but not without some expenditure of work either for maintenance of water quality or for disease treatment. Finally, feedlot mariculture, as pointed out by Bardach et al. (*14*), usually has the effect of restricting the operation to monoculture, which is ecologically inefficient.

Commercial turtle mariculture does not use the potential of the shallow seas to grow green turtles; "farming the seas" in this context is a slogan devoid of meaning. If the turtles are fed anything but marine grasses and algae after the first six to twelve months of life, they are exploiting a different food chain, and the main ecological value to man of *C. mydas* as a unique food source is eliminated. If, as is usually the case, trout chow and cheap fish are used to feed both hatchling and subadult turtles, the error is then compounded, because animal protein is being diverted away from a potentially more efficient and economical direct use by man. If an attempt is made to harvest *Thalassia* (or terrestrial crops) mechanically for food, then it becomes the de facto equivalent of moving the turtles to a higher trophic level, since human energy must be expended on work that the turtles would ordinarily do for themselves with much greater efficiency.

Reproductive problems

The second set of problems relates to reproduction and the associated natural history of the green turtle. In the preface to their book on aquaculture, Bardach et al. (*14*, p. viii), make the following statement: "Whether we wish to grow crab or mullet, lobster or shrimp and whether the first consideration is to make money or to supply additional animal proteins in a country's diet, we should have complete manipulative mastery over the entire life cycle of the animal. . . . *Control over reproductive biology* [authors' italics] of the species in question is necessary." Later in the same work the authors provide a systems flow chart for aquaculture planning in which they stress again that investigations of reproductive physiology should precede even the pilot project stage in the development of an aquaculture technology for any species.

In mariculture of sea turtles this sensible plan has been impatiently reversed: its proponents have begun large-scale commercial operations with the expressed hope of ob-

Figure 2. A green turtle lays her eggs at Bigisanti Beach, Surinam; the flask-shaped egg cavity has been exposed by the photographer. At this stage of nesting, the female is oblivious to interference. When egg laying is complete, the cavity will be packed with sand by the hind flippers and further covered with sand thrown by the front flippers. Ultimately, the eggs will lie almost a meter below the surface of the beach, necessitating a cooperative effort on the part of the hatchlings to emerge. (Photograph courtesy of Peter C. H. Pritchard.)

taining full control over the turtles' reproduction at some later date, but with no scientific certainty that this wish will ever be gratified. If a rational screening procedure had been used first, it is possible that the green turtle might have been eliminated by now as a candidate for mariculture.

At present, commercial mariculture is forced to parasitize natural nesting beaches for eggs to maintain its supply of turtles. This will continue into the foreseeable future, with several adverse consequences (*15*). Most obvious is the reduction of recruitment to the dwindling stocks of wild sea turtles caused by the loss of tens of thousands of eggs to mariculture. Since green turtles appear to return to their natal beaches to nest when they reach sexual maturity, losses from a particular population will not be made up from elsewhere, even if there were an "elsewhere" to provide replacements. A somewhat analogous situation in aquaculture has been described by Hickling (*16*), who reports that the eel (*Anguilla japonica*), which presents similar reproductive problems, is cultivated so intensively in Japan that the local supply of elvers is insufficient, with the result that elvers are imported from Taiwan and even from Europe (*A. anguilla*). Of course eels are not endangered to the same extent as green turtles.

It has been claimed by the advocates of mariculture that restoration of a small number of yearling green turtles will compensate for their egg predation, since most hatchlings do not survive to adulthood. The survivorship figure that they commonly quote is 0.2 percent; on the other hand, Hirth (*3*, p. 3:11), in the most extensive survey of the world literature on green turtles, states that survivorship to adulthood "may be as low as 1%." Thus, theoretically, a total of 20,000 eggs taken from one site could be replaced by 30 to 150 yearling turtles, depending on whose survivorship estimate is believed (and assuming a 75 percent hatching rate under natural conditions, as well as negligible mortality among the yearling group).

Unfortunately, the life cycle of the green turtle is so inaccessible that nobody knows whether yearlings (or older immature animals) can survive if released at the nesting beaches at the wrong time in their lives, or whether critical periods for the development of their orientation ability in response to local cues will have passed. Several authors (*17*) have suggested that hatchlings may be imprinted with the peculiar scent of their birthplace either while buried in the moist sand of the beach or while first swimming in the waters immediately offshore.

If olfactory or other local cues are indeed important in the development of homing ability, then yearling turtles, which may be past the age of imprinting, will not necessarily be able or motivated to return to the release site when they reach breeding age. Nor will they necessarily be able to sustain themselves with the same foods eaten by the more pelagic and carnivorous hatchlings as they drift or swim toward the distant feeding grounds. Indeed, the offshore waters at many nesting grounds (including Ascension Island and Tortuguero, Costa Rica) provide little or no food for turtles past the hatchling stage; adults on their reproductive migrations presumably sustain themselves by drawing upon extensive fat deposits not found in yearlings.

One known behavior pattern of the hatchlings that militates against manipulation of their life cycle has been described as the "infantile frenzy" (*18*). This is a period of incessant swimming activity seen in hatchlings that have freshly emerged from the nest and have been placed in water; it lasts for several days, after which the turtles begin to assume their lifelong activity pattern of sleeping at night and swimming during the day. Older freshly caught turtles do not display this peculiar behavior. If the infantile frenzy is a naturally occurring behavior and if it has any adaptive value, it is likely that it serves the purpose (when coupled with the appropriate orientation system) of taking the vulnerable hatchlings through the predator-infested inshore waters as quickly as possible. Equally significant, it might also serve to place the hatchlings in longshore currents that are moving toward the various feeding grounds.

In my own experience with laboratory-reared green turtles released at the age of one to two years in the Gulf of Mexico, several tagged individuals were recaptured a few days later when they crawled out of the ocean not far from the release point—certainly abnormal behavior for immature sea turtles. The same phenomenon has been observed by

Carr (pers. comm.). Therefore, although the natural history of the green turtle during the first year of life is largely unknown, circumstantial evidence supports the idea that being in the right place at the right time has developmental significance for the species. Considerations of this sort have prompted Hirth (*3*, p. 6:4) to remark that "hatchlings produced in . . . hatcheries should be released as soon as possible after emerging on the surface," with the method of release most nearly approximating "the natural behaviour of the animal." The release of yearling turtles at a nesting beach cannot be considered a substitute for eggs taken from that beach, on the basis of present knowledge.

Egg parasitism for commercial mariculture has another serious effect on the conservation of green turtles. Many of the nesting beaches are turtle sanctuaries or have laws and regulations prohibiting the taking of eggs by the native population. These sanctuaries and laws have been hard-won, often against political opposition, and are maintained only by their essential reasonableness and by the honesty and impartiality of their administrators. A hint of "colonialism" or foreign commercial exploitation of a resource denied to local citizens can reverse decades of hard work by ecologists and conservationists.

The impression made by foreigners using motorized vehicles to gather and remove 15,000 or 20,000 eggs in the course of a week or two is not easy to erase. How can an egg-hungry native be convinced that this is right and proper, if there is not even a convincing ecological rationale for such actions? The eggs taken for mariculture at Tortuguero beach, for example, would provide every child and adult in the two villages on the beach with two eggs a day for more than a month. Alternately, if we assume a very conservative 0.5 percent survival to maturity, these eggs represent the significant annual increment of 75 adult animals to replenish the dwindling turtle population at Tortuguero.

Conscious of the objections to

Figure 3. A weary female green turtle returns to the sea in the early morning hours after nesting, Great Barrier Reef. Nesting turtles may travel 100 meters or more inland, remaining out of water 1 to 4 hours, to deposit approximately 100 eggs. Several trips are made during the nesting season; this individual will nest again in 2, 3, or 4 years. (Photograph courtesy of Julie Booth.)

Figure 4. Mating green turtles are stranded by the receding tide, Great Barrier Reef. Most male sea turtles never return to land after their initial emergence from the nest, but are especially vulnerable to harpooning and capture while mating. (Photograph courtesy of Julie Booth.)

parasitizing natural nesting beaches for eggs, both commercial and nonprofit mariculturists are now working toward the goal of breeding green turtles in captivity and having the females nest on man-made beaches. Several instances of such breeding and nesting have been reported informally by different groups, but considerable research must yet be done before turtle "ranching" becomes turtle "farming"—in other words before the species has been reliably domesticated for its full life cycle. Manipulation of the reproductive cycle with pituitary and other gland extracts—usually requiring a lengthy process of experimentation—has not been attempted, nor has there been selective breeding for desirable traits (which will be complicated by a number of factors, including the storage of viable sperm in the female reproductive tract for a period of years).

Nevertheless, if we assume that all physiological and behavioral obstacles to turtle farming will be readily overcome, there remains a formidable ecological-economic problem which has not been discussed by the proponents of mariculture. None of the thousands of tagged green turtles has ever been observed to nest more often than every two years, most nest every three years, and many nest every four years (*19*). Let us assume the most favorable case for mariculture: that all captive females will be selected or induced to breed every two years, and that each will lay 500 eggs during a breeding season. We can also assume an overall 75 percent hatching rate, taking into account both fertility and incubation failures; this is midway between the high and low figures commonly encountered in practice. Finally, let us assume that one male will be adequate to fertilize ten females (*6*, p. 809). With these assumptions, a commercial turtle farm would have to keep a breeding stock of 293 adult sea turtles in order to provide 50,000 hatchlings a year. At 240 lbs (109 kg) each, a low-normal weight for adults, this is 70,320 lbs (31,937 kg) of green turtles to maintain on a permanent basis.

Where will these 293 sea turtles be kept with enough space for breeding and nesting, and how and what will they be fed? How will the pens (probably inlets with narrow necks connecting with the sea) be fenced against hurricanes and floods (when even a small break could cause ruinous losses of stock), how will they be cleaned, and what will happen to the excrement? And what will the cost of all this do to the already high price of the product? It is clear that the advocates of self-sufficient turtle farms have not thought this out with any degree of precision. True, other mariculture industries have overcome many difficulties and now control the full life cycle of their organisms. But it is a far cry, for example, from a kuruma shrimp that reaches an adult size of 50 to 120 g in a few months and produces 300,000 to 1,200,000 eggs (*14*, pp. 602–10) to a green turtle weighing 109 kg and producing 500 eggs every two years. Nor is it even remotely likely that the difference will made up by the difference in the profit per shrimp versus the profit per turtle.

Economic problems

The third set of major problems concerns the interaction between economics and conservation and can be generalized, with caution, to a number of other commercial ventures in the farming of endangered species. To begin, there is the irreducible and increasing cost of feeding animal protein, even in the form of trash fish and trout chow, to sea turtles (*20*). When added to the costs of either obtaining eggs or breeding adults, plus the intangible costs and risks associated with raising a crop that takes two to three years to reach marketable size, it becomes clear that the various turtle products will always be sold at luxury prices. No amount of production efficiency will eliminate the extra costs imposed by the biological and ecological peculiarities of green turtles; they are not economically homologous with chickens. In the words of Russell-Hunter (*21*), "provision of animal food is expensive . . . and generally can only support a luxury trade."

No kwashiorkor will ever be nipped in the bud by a traditional serving of jellied turtle broth with sherry at a banquet of the Lord Mayor of London, or by the sale of a turtle steak in a New York gourmet shop or Florida supermarket. As long as large-scale mariculture of sea turtles is returning a profit, it represents a waste of animal protein on an expensive trophic level and is a negative factor in the global supply of protein in the human diet. There is perhaps no better example of a tight, direct linkage between ecology and economics.

Another economic problem with mariculture's relationship to conservation has been suggested by Carr (*22*). The mariculturists engaged in raising green turtles as a commercial operation are bound to make every effort to strengthen and broaden the market for turtle products. Yet for the reasons just noted, they will never be able to bring the prices of those products so low that the fishing of wild stocks becomes uneconomical, at least not until *Chelonia mydas* is reduced to such tiny and inaccessible populations that it is commercially extinct. In fact, by generating a new market demand, they are likely to make both legal and illegal turtle fishing more attractive than ever (*23*). The revival and stimulation of the luxury goods trade in turtle products ensures that there will always be some market outlets for anybody who has turtles to sell.

Competitive "barriers to entry" are not effective in situations of this sort, where the "competition" consists of a highly flexible network of turtle fishermen and distributors who have little capital investment in turtling, are responsive to sudden opportunities in local as well as international markets, and can fish for something else whenever the demand for turtles slackens. If turtles are profitable to the mariculture industry, they will be profitable to turtle fishermen; because of its high overhead it is not possible for mariculture to remove permanently the sellers of wild-caught sea turtles from the market by pricing strategies—nor is there any economic reason even to make the attempt.

A roughly analogous situation can be seen in central Florida, where the mere existence of Disney World, with its proven ability to draw millions of tourists from all over the country, has stimulated the growth of dozens of "rival" tourist attractions and facilities, many of which are poorly capitalized and badly managed and might fail in the absence of their giant "competitor." Unfortunately, the demand for turtles will grow with mariculture, and so will the price of the products.

It has been countered that commercial mariculture will monopolize the turtle trade because of the reliability and volume of its turtle output and because of the higher quality of the meat, leather, and shell (but not calipee or oil) it has for sale. In the former case, the argument is easily dismissed because it applies only to certain types of large volume purchasers. In the latter, the superiority of the domestic products is not overwhelming, except perhaps in the

Figure 5. Hatchling green turtles explode out of their nest cavity and begin a frantic dash across the predator-infested beach to the slightly less dangerous sea, Great Barrier Reef. Emergence is temperature-dependent, usually occurring after midnight—rarely during a cool overcast or rainy day. The hatchling emergence is hardly ever seen. (Photograph courtesy of Julie Booth.)

case of shell (24). But whatever the difference in quality, it could hardly be great enough to cancel out the high operating costs of the mariculture industry, and turtle fishermen can easily afford to sell their products at a lower price, if necessary.

There are two last objections to commercial mariculture of sea turtles, which I mention briefly because they do not necessarily bear on turtle conservation. First, mariculture is now obtaining eggs from a number of nesting beaches in different parts of the world. An accident or natural disaster such as a hurricane might result in the release into the ocean of large numbers of mariculture hatchlings from different gene pools. This in turn could conceivably, in subsequent years, cause the distortion or obliteration of natural zoogeographic patterns of great interest to biologists. Second, there is the whole issue of secrecy, which may be necessary to a commercial operation, but which is repugnant to scientists who are thus obstructed in their efforts to learn more about the physiology, behavior, and management of sea turtles.

Domestication: costs and benefits

I have advanced arguments to show that the large-scale commercial mariculture of green turtles is at present having a negative influence on efforts to conserve this endangered and uniquely valuable reptile. Moreover, ecological and economic constraints that the industry cannot escape appear to guarantee that the effect of commercial mariculture on conservation will continue to be adverse in the foreseeable future. The problems include: (1) parasitizing natural populations for eggs; (2) undermining local conservation regulations; (3) the difficulty of developing and maintaining a breeding stock; (4) the inability to benefit from the animal's favorable trophic position, with the resulting waste of animal protein and high operating costs; and (5) reviving the demand for turtle products and thus increasing the economic pressure on remaining wild populations. These problems seem to lack a simultaneous solution. Indeed some of them appear to have no solution at all.

Carr has recently questioned whether the commercial farming of wild animals can help save any of the most endangered reptiles—sea turtles, alligators, and crocodiles (22). This case study lends support to his worries about farming insofar as sea turtles are concerned, but the biological peculiarities of *Chelonia* should make us cautious in extending this conclusion to members of other reptilian orders.

Nevertheless, the example of the green turtle does provide a useful generalization pertaining to an interaction between economics and ecology, which can be applied whenever a commercially valuable species is declining. Specifically, in any case of wild animal farming (or ranching) there must come a critical point in the relationship between farming and hunting at which hunting is no longer worthwhile because of relative costs; at this point farming becomes a positive factor in conservation. The location of this point is established, on the one hand, by the number of animals produced by farming, the cost per animal, and the added demand generated by the industry, and on the other, by the availability (cost) of wild animals, which is itself a complex function of population size, distribution, and behavior. (This critical point should not be confused with the point at which wild animal farming becomes profitable; the latter is a subject for more conventional economic analysis and is outside the scope of this article.)

Figure 6. The path of a nesting green turtle stretches across the beach at Isabela Island, Galapagos. This bulldozerlike track can serve as an arrow indicating the location of eggs, and possibly the turtle herself, to an experienced poacher. The reproductive behavior of green turtles, which includes aggregate nesting at specific beaches, is largely responsible for the endangered status of the species. (Photograph courtesy of Peter C. H. Pritchard.)

With large, slowly maturing, partially carnivorous, easy-to-catch animals, the example of the green turtle has demonstrated that the critical point may be reached only when the wild populations near (or reach) extinction. Thus the existence of commercial farms for alligators and crocodiles should not be allowed to generate the false confidence that the conservation problems of these species have been solved.

It remains to be asked whether other methods of raising captive green turtles might be more acceptable to conservationists. As is often pointed out, the greatest conservation potential of sea turtle mariculture occurs when it substantially increases survivorship during the first year of life. This can, in effect, liberate the considerable sea turtle fecundity for the task of rebuilding depleted populations. But for this to happen, many of the turtles so raised must be released rather than marketed, and there must be a reasonable chance of their survival. These conditions have the best chance of being satisfied by nonprofit turtle ranches located at nesting beaches that also have resident colonies of green turtles.

One positive approach to nonprofit turtle ranching can be seen at Great Inagua Island, Bahamas, where the Caribbean Conservation Corporation and Bahamas Trust have taken advantage of a favorably indented coastline to wall off about 1,000 ha of turtle-grass shallows. Both hatchlings and adults can be kept there, and one instance of nesting on a man-made beach has already occurred.

Commercial mariculture of sea turtles is occasionally acceptable, but only when the operations are *small* and under government supervision, and when the markets are relatively local. The turtle ranches established in Queensland, Australia, by Dr. Robert Bustard (*7*, pp. 179–88) are an excellent example: they serve the dual function of interesting the native population in turtle conservation and reducing the local hunting pressure on wild stocks (because the hunters are involved in the ranching). In this case the advantages appear to outweigh the usual negative side effects of turtle mariculture, but periodic reevaluation will be advisable.

The best procedural rules for green turtle mariculture can be found in the writings of Hirth, who advises that "initial attempts at turtle aquaculture should be on a small scale and should be conducted only if scientific expertise is available" (*3*, p. 7:1), and Carr, who states that "the only effort to be encouraged should be a non-profit, government-sponsored campaign in which many small, widespread, purely experimental projects simultaneously attack the problems of nutrition, disease control, and captive breeding; and which, from the beginning, freely share all information bearing on procedure and results" (*22*). The conservation lesson of green turtle ranching is plain: not all animals are equally appropriate for large-scale commercial husbandry, and the multiple interactions among biology, economics, and conservation must be carefully weighed at the outset.

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9. J. Parsons. 1962. *The Green Turtle and Man.* Gainesville: University of Florida Press, pp. 25, 28.

10. R. Ingle and F. Smith. 1949. *Sea Turtles and the Turtle Industry.* Miami: University of Miami Press, p. 46.

11. H. Hirth, ref. *3*, pp. 2:1–2:8. W. Rainey, and P. Pritchard. In press. *Trans. N. Am. Wildlife and Nat. Res. Conf.* R. Honnegger. 1968, 1970. *Red Data Book 3; Amphibia and Reptilia.* Morges, Switzerland: IUCN.

12. At the time of this writing, the only large commercial operation for raising green turtles (and other species) is Mariculture, Ltd., based on Grand Cayman Island, B.W.I. Their stock consists of approximately 40,000 sea turtles of various ages. Throughout this paper my use of the word *mariculture* refers to the process in general and not to this particular firm. Although I am highly critical of the effect of mariculture on sea turtle conservation, I have no specific quarrel with Mariculture, Ltd., whose officers have always been helpful and courteous.

13. B. Commoner. 1972. *The Closing Circle.* New York: Knopf, pp. 146–51.

14. J. Bardach, J. Ryther, and W. McLarney. 1972. *Aquaculture.* New York: Wiley-Interscience, p. 11.

15. I thank Dr. Nicholas Mrosovsky for calling to my attention an interesting series of letters in *The Times* (London) concerning the problem of the removal of green turtle eggs from nesting beaches for use in commercial mariculture. In these letters, Dr. Mrosovsky (University of Toronto), Dr. K. E. L. Simmons (University of Leicester), and Mr. Nigel Sitwell (World Wildlife Fund) argue that mariculture has not yet demonstrated that it has the potential to aid in the conservation of sea turtles, while at present it constitutes a net drain on wild populations. The mariculture position was defended by Mr. Irvin Naylor (Mariculture, Ltd.) and Mr. Brian Lusty (John Lusty, Ltd.). See *The Times:* Aug. 28, Sept. 22, Sept. 27, Nov. 22, and Nov. 29 (1972).

16. C. Hickling. 1971. *Fish Culture.* London: Faber and Faber, p. 186.

17. A. Koch, A. Carr, and D. Ehrenfeld. 1969. The problem of open-sea navigation: the migration of the green turtle to Ascension Island. *J. Theor. Biol.* 22:163. M. Manton, A. Karr, and D. Ehrenfeld. 1972. An operant method for the study of chemoreception in the green turtle, *Chelonia mydas. Brain, Behav. Evol.* 5:188. D. Ehrenfeld. 1972. *Conserving Life on Earth.* New York: Oxford University Press, p. 302. A. Carr. 1972. The case for long-range chemoreceptive piloting in *Chelonia*. In S. Galler, K. Schmidt-Koenig, G. Jacobs, and R. Belleville, Eds., *Animal Orientation and Navigation.* Washington, D.C.: NASA, pp. 469–83.

18. A. Carr. 1972. In *Animal Orientation and Navigation*, pp. 473–74. See ref. *17*.

19. J. R. Hendrickson. 1958. The green sea turtle, *Chelonia mydas* (Linn.) in Malaya and Sarawak. *Proc. Zool. Soc. Lond.* 130:455. R. Bustard. ref. 7, p. 132. A. Carr and M. H. Carr. 1970. Modulated reproductive periodicity in *Chelonia*. *Ecology* 51:335.

20. Poikilothermy might be expected to be an advantage here, because of the dietary energy saving as compared with domestic animals that must maintain a high body temperature. Although this energy "saving" would clearly result in decreased consumption (per unit of turtle body weight) of carbohydrates and fats, it would theoretically reduce somewhat the need for dietary protein as well. This theoretical advantage, however, has not so far been reflected in the protein conversion efficiencies that have been observed in fish, which are also poikilothermic. According to G. L. Rumsey (Director, Tunison Laboratory of Fish Nutrition, Cortland, N.Y.; pers. comm.), it requires approximately 182 g of dietary protein to produce the 82 g of protein in a pound of broiler chicken, giving a protein conversion efficiency of 45 percent. Figures as high as 64 percent efficiency have been reported for broiler chickens. On the other hand, typical protein conversion figures for trout range from 22 percent to 54 percent efficiency, and the higher figure was obtained with an expensive diet of living brine shrimp. Of course, as Rumsey points out, the chicken is better known nutritionally and perhaps better controlled genetically than any other domestic animal in the world, while fish nutrition is still poorly understood; nevertheless, the protein conversion data for many species of fish give little encouragement for the hope that poikilothermy in domesticated animals will facilitate substantial savings in dietary protein (or even calories).

21. W. Russell-Hunter. 1970. *Aquatic Productivity.* New York: Macmillan, p. 279.

22. A. Carr. 1972. Great reptiles, great enigmas. *Audubon* 74:24.

23. ———. 1969. Sea turtle resources of the Caribbean and Gulf of Mexico. *IUCN Bull. (New Ser.)* 2:74.

24. Although green turtle shell from pen-raised animals is better than shell from older, wild-caught individuals, a resuscitated tortoiseshell market will have the disastrous side effect of increasing the pressure on wild hawksbill turtles *(Eretmochelys imbricata)*, the world's most endangered sea turtles, whose shell is equal or superior to anything mariculture can provide from green turtles.

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