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Do Open-Cycle Hatcheries Relying on Tourism Conserve Sea Turtles? Sri Lankan Developments and Economic–Ecological Considerations

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ABSTRACT / By combining economic analysis of markets with ecological parameters, this article considers the role that tourism-based sea turtle hatcheries (of an open-cycle type) can play in conserving populations of sea turtles. Background is provided on the nature and development of such hatcheries in Sri Lanka. The modeling facilitates the assessment of the impacts of turtle hatcheries on the conservation of sea turtles and enables the economic and ecological consequences of tourism, based on such hatcheries, to be better appreciated. The results demonstrate that sea turtle hatcheries serving tourists can make a positive contribution to sea turtle conservation, but that their conservation effectiveness depends on the way they are managed. Possible negative effects are also identified. Economic market models are combined with turtle population survival relationships to predict the conservation impact of turtle hatcheries and their consequence for the total economic value obtained from sea turtle populations.

Open-cycle turtle hatcheries are now well established in Sri Lanka and some other developing countries. These hatcheries depend on the collection of sea turtle eggs from the wild to provide their turtle stock and mainly rely on tourists for their continuing economic viability. The purpose of this article is to outline the nature of this industry in Sri Lanka and to consider the conduct, possible motivation, and performance of managers of these hatcheries, especially in relation to turtle conservation. A further aim is to show how simple economic analysis can be used to examine changes in the market for harvested turtle eggs following the establishment of open-cycle hatcheries and combine this with basic ecological considerations, in order to determine the consequences of the hatcheries for conservation of sea turtle populations. A subsidiary theme (requested by one of the reviewers) involves considering the total economic value of sea turtles and the possible dynamic impacts of the presence of hatcheries on the total economic value of sea turtles.

KEY WORDS: Nature conservation; Sea turtles; Developing countries; Sri Lanka; Sea turtle hatcheries; Total economic value; Tourism

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The above issues are particularly important given the reported conservation status of sea turtles. All seven species of sea turtles, except the Australian flatback (*Natala depressus*) are classified by the International Union for the Conservation of Nature (IUCN 2003) as either critically endangered or endangered, and all species are included in Appendix I of CITES (2004). This classification is, however, disputed. Meylan (1998) and Mrosovsky (2000, 2003), in particular, argue that the degree of endangerment is overstated by the IUCN. Those species listed as endangered (but not critically so) are the loggerhead, green turtle, and olive ridley. Hatcheries in Sri Lanka are mostly stocked with these species. However, hawksbills are sometimes hatched also.

Sea turtles face several threats, both on land and at sea (Marcovaldi and Thome 1999; NRC 1990). A major threat to the survival of sea turtles in developing countries is the collection of eggs for human consumption (Shanker and Pilcher 2003; Pilcher and Ismail 1999; Pilcher 1999; Marcovaldi and Thome 1999; Richardson, 1994). Furthermore, in some developing countries where eggs are used for human consumption, eggs are also collected for sea turtle hatcheries that cater to tourists. This occurs, for example, in Sri Lanka (Amarasooriya 2001) and in some other developing countries (Chantrapornsyl 2002).

Turtle hatcheries could have closed or open cycles for production of their turtle stock. Open-cycle hatcheries rely for their ongoing operations on continuing collection of stock (eggs, hatchlings, or broodstock, depending on the case) from the wild. Closed-cycle hatcheries, on the other hand, do not depend on recruitment of stock from the wild but possess a self-contained reproductive cycle. The degree of openness of hatcheries can also vary. Those in Sri Lanka are very open, relying solely on egg collection from the wild. After the eggs are collected from the wild and have hatched, the hatchlings are held for a few days before being released to the sea.

Many open-cycle turtle hatcheries try to justify their existence on the basis that they help conserve the population of sea turtles by saving eggs from being consumed by humans (Gampell 1999). Sea turtle hatcheries are used as an *ex situ* conservation tool (i.e., one operating outside the natural environment) in many countries (Shanker 2003; Chan 2001; Upm and Perhilitan 1996; Shanker 1994; NRC 1990). However, in this case, the conservation measures only operate *ex situ* for a part of the turtle's life cycle.

Doubts have been raised about the conservation benefits of such operations (Hewavisenthi 1993), as is also the case for some other ecotourism ventures intended to generate money to support conservation (Stone and Wall 2004). Nevertheless, it is widely accepted that well-managed sea turtle hatcheries can play a positive role in turtle conservation when *in situ* conservation (conservation of turtles in their natural environment) is not possible or is impractical (Chan 2001; IUCN/SSC Marine Turtle Specialist Group 1999; IUCN 1995).

Close Connections Between the Operation of Sea Turtle Hatcheries and Tourism in Sri Lanka

A strong correlation is present between the numbers of sea turtle hatcheries and quantity of eggs collected for hatcheries and tourism in some developing countries. For example, in Sri Lanka, the highest density of tourists is in the southwest of the country and the number of hatcheries is also highest there. It is claimed that owners of some sea turtle hatcheries are not mainly motivated by conservation aims, but rather by commercial gains from tourists. In fact, some of these hatcheries operate only during the tourist season (Hewavisenthi 1993) and, for most, tourism is essential to their economic viability.

Amarasooriya (2001) argued that because some Sri Lankan hatcheries only operate during the tourist season, this demonstrates that the prime motive of such hatcheries is profit rather than conservation. This is because, in his view, their profits during the main tourist season would be sufficient to finance their hatchery activities in the off-season. However, because their tourist revenue in the off-season is less than their operating expenses (variable costs), they might generate more profit by ceasing their conservation efforts and closing down their hatcheries in the tourist off-season.

A substantial quantity of sea turtle eggs are collected for human consumption in several Asian developing countries (e.g., in Sri Lanka, Indonesia, Malaysia, and India) (Amarasooriya 2001; Pilcher 1999) and in non-Asian countries as well (Marcovaldi and Thome 1999). With the development of turtle hatcheries, the price of collected turtle eggs often increases due to competition between hatcheries and those individuals who buy turtle eggs to eat. In Sri Lanka, five species of sea turtles nest throughout the year in significant numbers (Amarasooriya 1999), although the numbers nesting decrease in some months in certain areas. During the months of low supply, human competition for eggs becomes intense.

Chan (2001) claimed that sea turtle hatcheries can make a positive contribution to sea turtle conservation if they are managed using appropriate scientific guidelines. This is especially so when *in situ* conservation is expensive and impractical. However, if hatcheries are not well managed, survival rates of hatchery-released turtles might be lower than in the wild. Furthermore, account should be taken of the possibility that the market for turtle eggs for incubation in hatcheries could result in increased harvest of eggs that would otherwise hatch in the wild. Economic and ecological analysis can be combined (as is the main objective here) to identify the possible consequences for sea turtle conservation of turtle hatcheries reliant on economic support from tourists. This is an important matter because a large number of turtle eggs are collected each year in Sri Lanka and in some other developing countries to supply hatcheries. It is estimated that almost one-third of a million turtle eggs was collected in Sri Lanka in 2000 to supply hatcheries. Before presenting the economic–ecological analysis, some background is presented about the nature of sea turtle hatchery-based tourism in Sri Lanka.

The Nature of Sea Turtle Hatchery-Based Tourism and Hatchery Operations in Sri Lanka

Hatchery-based *ex situ* conservation practices are widespread in sea turtle conservation (Shanker 2003;

Chan 2001; NRC 1990). Closed-cycle turtle hatcheries are rare, but one has been established in the Cayman Islands for green turtles. The procedure of many open-cycle hatcheries is to secure turtle eggs laid on unprotected beaches by removing them and incubating them under protected conditions and releasing the hatchlings back into the ocean. This practice is well established in Sri Lanka. This way eggs are protected from threats, including egg collectors who sell the eggs for human consumption, predators, damage by beach users, and the possibility of eggs being washed into the sea during rough and high seas. This practice can ensure higher hatchling rates than otherwise and affords protection to hatchlings until they are released to the ocean. This procedure normally requires purchase of eggs from local village egg collectors.

Sea turtle eggs in Sri Lanka on most beaches, and in many (but not all) developing countries, are virtually open-access resources. In Sri Lanka, and in some other countries, sea turtle eggs are only to some extent open-access resources because their collection is restricted to members of the village that has a *de facto* claim on the beach (and its resources) where the eggs are laid. This is usually a village adjoining the beach. However, because access to turtle eggs deposited on its beach is not collectively regulated by the village, the resource is effectively an open-access one for all of its villagers. It is well known that in cases where economically valuable biological resources are subject to open access, serious economic and conservation failures can occur and valuable species risk being driven to extinction (see, e.g., Gordon 1954; Hardin 1968; Tisdell 2002, Chap. 8; Witherington and Frazer 2003). However, once turtle eggs are collected and sold to hatcheries, they become, in effect, private property and can be protected by their ''owners.'' The operation of hatcheries transforms the environmental situation from one of open access to one that involves a combination of open access and private property for different parts of the life cycle of the sea turtle.

It has been suggested that in some cases, private ownership of wildlife might be an effective means for conserving species (Swanson 1994; Skonhoft 1999). Specific identifiable ownership and legal responsibility have been suggested as being necessary for the conservation of sea turtles (Eckert 1991; Crowder 2000; Witherington and Frazer 2003, p.367). The matter is, however, complicated when animals are highly mobile or fugitive because it might be very costly or virtually impossible to enforce private property rights (Ciricacy-Wantrup 1952). The turtle case, that we analyze in this article, however, is one in which the biological resource is an open-access resource for parts of its life cycle, and private property for another part of that cycle, namely for eggs in hatcheries.

Several tourism-associated turtle hatcheries have existed in Sri Lanka for decades (Shanker 2003; Pritchard 1980; Wickramasinghe 1982; Fernando 1977), despite the collection of turtle eggs from the wild being illegal in Sri Lanka. The main objective of these hatcheries has usually been to prevent eggs from being used for human consumption, to hatch these, and to release hatchlings with a view to maintaining populations of sea turtles. These hatcheries have now become an important tourist attraction in Sri Lanka (Mackensen 2002). Hatcheries catering to tourists hold hatchlings in small artificial seawater ponds for a few days after they are hatched before releasing them to the ocean nearby. The hatchery program involves ranching to some extent and the ''justification'' of its proponents is that it provides baby turtles with a head start, claimed to result in a larger number of marine turtles surviving in the wild than would occur without this intervention (Gampell 1999). This contention has, however, been disputed by Frazer (1992), who reviewed early literature dealing with this subject. Sri Lankan hatcheries also normally hold a few subadult or adult turtles to provide extra interest to tourists.

Showing sea turtles to tourists, especially hatchlings, is a more lucrative business than using eggs for human consumption (Amarasooriya 1999). Hatcheries generate income from tourists in several ways. First, tourists are charged to view sea turtle hatchlings in holding tanks and they are encouraged to view hatchlings emerging from their eggs, and to release hatchlings to the ocean for a payment. Furthermore, there is the incidental sale of souvenirs to tourists. In addition, tourists also donate money at these hatcheries for sea turtle conservation. Therefore, there is ''value adding'' to eggs that might otherwise have been consumed directly.

All sea turtle hatcheries in Sri Lanka are open to visitors to view hatchlings and a few adult turtles. Visitors can see fenced sandy areas where the turtle eggs are being incubated and can view and even hold hatchlings housed in seawater tanks, and a few adult turtles are usually on display. Guides might provide some interpretation for visitors. This type of manipulation of nature is promoted by operators of hatcheries as a form of ''ecotourism'' and claimed to make a positive contribution to the conservation of marine turtles (Gampell 1999) because the money generated from tourism (e.g., entrance fees and donations) is reinvested in purchasing eggs from collectors that otherwise would be consumed. Initially, turtle hatcheries were started in Sri Lanka with the prime objective

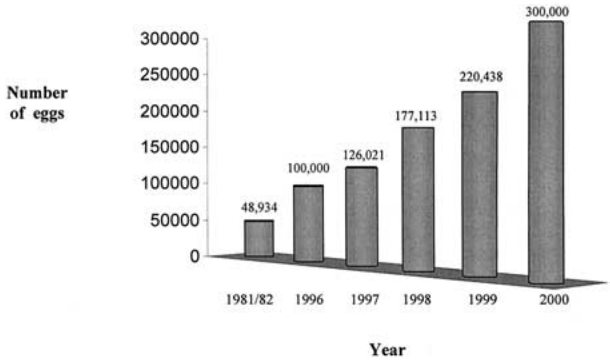

Figure 1. Number of sea turtle eggs used in hatcheries in Sri Lanka. Data for 1981/1982 from Wickramasinghe (1982) and data for 1996–2000 from Amarasooriya (2002).

of sea turtle conservation only in mind (Wickramasinghe 1982; Fernando 1977). However, according to Amarasooriya (2001), only two of the nine hatcheries in operation in Sri Lanka today (less than 20%) have conservation in mind as their main objective, and the rest are maintained primarily for commercial gains.

It is, however, often difficult to determine the main objective of an enterprise, especially a turtle hatchery. Furthermore, the desire for commercial gain need not be inconsistent with the promotion of nature conservation, as is clear from the analysis given later in this article.

The number of sea turtle hatcheries in Sri Lanka has fluctuated in recent years. Richardson (1994) recorded 16 hatcheries in the southwestern and the southeastern coast, but this number declined to 7 in 1996 (Amarasooriya and Dayaratne 1997). By the end of 2000, there were nine such hatcheries (Amarasooriya 2001). In recent years, there has been a tendency for the average size of hatcheries to increase, as measured by their annual average utilization of eggs. On average, each hatchery reburied ~19,311 eggs in 1981/82, 14,286 eggs in 1996, and 33,333 eggs in 2000, as can be seen by dividing egg numbers given in Figure 1 by the number of establishments.

Figure 1 indicates that the number of eggs taken by hatcheries has shown a phenomenal increase. In 1981/1982 (data available only from early December 1981 to early May 1982) only 48,934 eggs were used in 3 hatcheries (Wickramasinghe 1982). At that time, hatcheries had few tourists and were mainly used for conservation. However, the number of eggs purchased by hatcheries increased as sea turtle hatcheries became major tourist attractions, and in 2000, it is estimated that 300,000 eggs were used by hatcheries.

The overriding importance of tourism for some hatcheries is underlined by the fact that they only operate during the main tourist season (Hewavisenthi 1993). This results in the number of collected eggs used in hatcheries fluctuating according to the tourist season. In Sri Lanka, turtles nest throughout the year, with the peak season occurring for the Galle district (covers sea turtle nesting sites in the southwestern coast) in the period November to May and for the Hambantota district (covers sea turtle nesting sites in the southeastern coast) in the period May to August (Amarasooriya 1999). See Figure 2 for those locations.

Data collected by Amarasooriya (2001) show that the largest collection of eggs reburied by the hatcheries coincides with the peak tourist season, which starts in November/December and continues to April/May, and that use of eggs by hatcheries declines during the low tourist season. Most eggs utilized by hatcheries are acquired on the southwestern coast of Sri Lanka (Amarasooriya 2001). These account for 98% of eggs utilised by hatcheries in Sri Lanka and the remaining 2% are utilized in the southeast of the island (Amarasooriya 2001). See Figure 2 for the location of two main districts where the majority of eggs are used.

Two factors probably help to explain the difference. Tourism is concentrated on the southwest coast of Sri Lanka rather than the southeastern coast, partly because of the closer proximity of the southwestern coast to Colombo. This makes for a relatively higher demand for tourism-based hatcheries in the southwest than in the southeast. Second, the peak turtle-nesting season in the Galle district virtually coincides with the peak tourist season. Both extend approximately from November to May. However, in the Hambantota district, there is virtually no overlap of the peak tourism period with the peak nesting season for turtles (May to August inclusive in this district) and the period of peak nesting of turtles is shorter in the Hambantota district than in the Galle district. Seasonal tourism demand combined with favorable supplies of turtle eggs provides an economic advantage for hatcheries in the Galle district compared to those in the Hambantota district.

Amarasooriya (2001) estimates that the annual revenue obtained by hatcheries in Sri Lanka is more than Rs 27 million a year or approximately US $340,562. The number of egg collectors is estimated to be 35 and the hatcheries provide direct employment to ~175 persons who support over 650 dependents (Amarasooriya 2001).

In Sri Lanka, not all collected eggs are used in hatcheries, unlike in some places in Malaysia (Chan 2001). Amarasooriya (2001) estimates that around 33% of the eggs collected in Sri Lanka are used in hatcheries. This number is increasing as can be seen from Figure 1. This means that about two-thirds of sea turtle

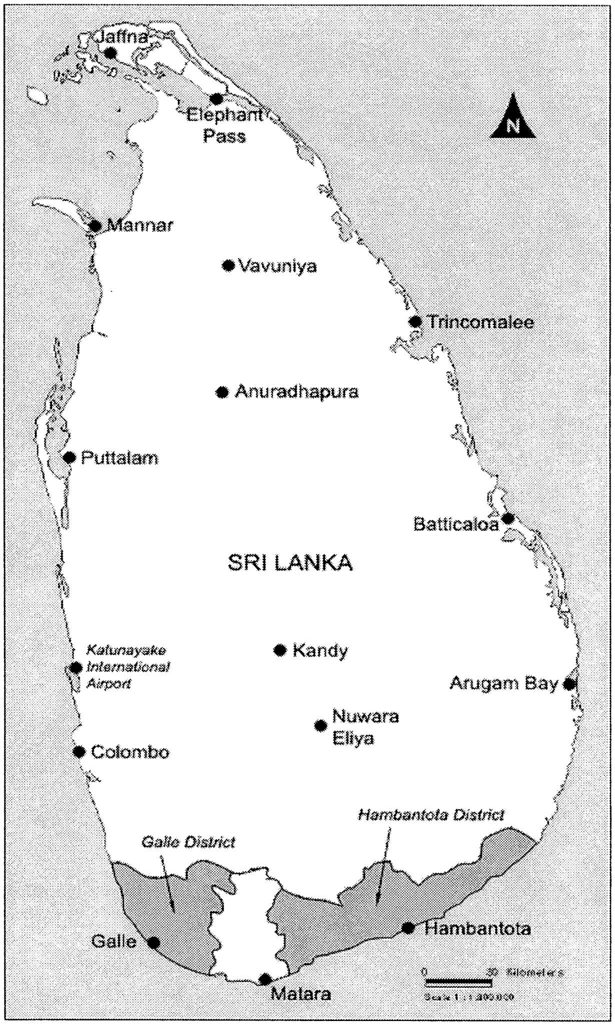

Figure 2. Map of Sri Lanka showing the Galle and hambantota districts, the only locations for turtle hatcheries in Sri Lanka.

eggs collected in Sri Lanka are currently consumed. The trend is for this proportion to decrease, but not the number of eggs consumed.

The following arguments (see, e.g., Mortimer 1999) are put forward by those emphasising the positive contribution of turtle hatcheries to the survival of populations of sea turtles.

1. Turtle eggs that might have otherwise been collected and eaten by humans are supplied to the hatchery because it pays for those eggs. These are hatched and contribute to the maintenance of turtle populations.
2. Under hatchery conditions, eggs are afforded greater protection from land-based natural predators and so a larger number of eggs remain to produce hatchlings.
3. Furthermore, hatchlings obtain greater protection under hatchery conditions from natural predators than occurs in the wild and can be released to the ocean at a propitious time, when few predators, such as birds, are likely to kill them.
4. Nursery hatchlings can also be released at places where they will not be attracted inland by lights and consequently perish.
5. A further advantage could be that villagers who collect turtle eggs for the hatchery trade might dissuade other collectors from collecting these eggs for human consumption. Trade in turtle eggs for human consumption often persists in developing countries despite it being illegal.

Although those consequences are possible, the final results depend on how well the hatcheries are managed. Some managerial criticisms of hatcheries include the following: (1) hatcheries could produce 100% female hatchlings (Shanker and Pilcher 2003); (2) hatchery-raised hatchlings could carry disease (Higgins 2003); (3) hatchlings could become too weak if they are raised in tanks for long periods of time without appropriate care (Hewavisenthi and Kotagama 1990); (4) hatchlings held in crowded tanks are more likely to cause injury to each other (Hewavisenthi 1993); (5) marine predators are likely to become more effectively focused on hatchlings when they are released from a few beaches, especially at set times (Pritchard 1980) and predation rates might rise; (6) hatchlings raised in tanks, even for a few days, could lose their ''imprinting mechanism,'' which is thought to be necessary to enable adult females to return to the same beach to nest (Pritchard 1980); (7) releasing hatchlings only from a few beaches could, in the long term, affect the nesting distribution and species' composition; (8) handling of eggs and their transportation, especially for long distances, could increase the mortality rates of hatchlings; (9) handling of hatchlings by tourists and the practices of digging up transplanted nests to show visitors and allowing tourists to release hatchlings during the day could adversely affect hatchlings (Hewavisenthi 1993) and, in some cases, the natal homing instincts of turtles might be weakened by the period of their stay in hatcheries. However, all these problems can be addressed in principle, and guidelines for the appropriate maintenance of hatcheries have been formulated (cf. Higgins 2003; Mortimer 1999; IUCN/SSC Marine Turtle Specialist Group 1999).

The conservation consequences of turtle hatcheries depend not only on ecological factors but also on economic considerations. Economic analysis can, for example, be used to scrutinize claims that hatcheries reduce the number of turtle eggs consumed by humans. Because both aspects are important for turtle conservation, let us formally take into account economic and ecological analysis.

Analysis: Economic Considerations

Simple economic market demand and supply analysis can be used to specify the likely impact of open-cycle turtle hatcheries on the price of turtle eggs, on the number of eggs collected on the quantity of these used for consumption, and on the amount of eggs supplied to hatcheries. Take the example shown in Figure 3, in which normal market supply and demand curves for harvested turtle eggs are assumed.

In Figure 3, X_3 is assumed to be the total number of sea turtle eggs of all species laid on relevant beaches in a period of time, and the line SS represents the supply of harvested turtle eggs at alternative prices for these. Suppose that the demand for harvested turtle eggs for consumption exists as shown by the line marked D_cD_c. Then, in the absence of demand from hatcheries for eggs, the market equilibrium for harvested turtle eggs is E_1. Prior to turtle hatcheries, turtle eggs sell for P_1 each and X_1 eggs are harvested in the period. $X_3 - X_1$ eggs remain unharvested.

Suppose now that an additional demand for turtle eggs arises from hatcheries, due to tourist demand, while all other factors remain the same. In Figure 3, the total demand for turtle eggs consequently shifts rightward, as indicated by the demand curve marked D_TD_T. The difference between this line and the line marked D_cD_c represents the extra demand generated by hatcheries for eggs. A new market equilibrium is now established at E_2. Consequently, the equilibrium price of eggs rises to P_2 and the harvest of eggs rises to X_2. Therefore, fewer eggs, $X_3 - X_2$, are now left to hatch in the wild.

The extra supply of eggs for the hatcheries comes from two sources: (1) eggs that would otherwise be consumed, a substitution effect, $X_1 - X_0$ in the case shown in Figure 3 and (2) from increased harvesting of eggs from the wild ($X_2 - X_1$). If the demand curve for turtle eggs for consumption is steeper than that of the supply curve, the largest share of the increased turtle nursery supply will come from increased harvesting of eggs. If the reverse relationship holds, the opposite conclusion follows.

If the demand for harvested eggs for hatcheries becomes very high, then there is a tendency for virtually all eggs laid in the wild, possibly including those on

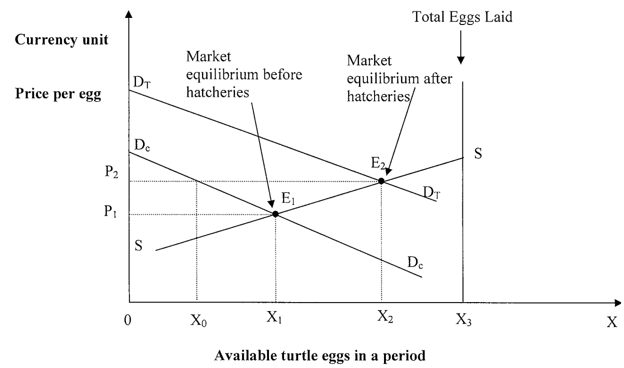

Figure 3. Demand and supply relationships for harvested turtle eggs. Market equilibrium for turtle eggs shown before (E_1) and after (E_2) the presence of hatcheries.

remote beaches and national parks, to be collected. The consumption of eggs might also fall to low levels. The prospects for survival of populations of turtles will then increasingly come to depend almost completely on turtle hatcheries.

Sri Lanka is, however, still far from a situation in which all (or the major portion of) of its collected turtle eggs are utilized in the hatcheries. Currently, about 1 million eggs are being collected annually in Sri Lanka, of which about two-thirds are consumed and one-third are used by the hatcheries (Amarasooriya 2001). Thus, in Figure 3, in the Sri Lankan case, X_0 would be comparatively much greater than indicated (about two-thirds of 1 million eggs annually) and $X_2 - X_0$ much smaller, about one-third of 1 million eggs annually.

Note that the more inelastic the demand for turtle eggs for human consumption is, the smaller will be the substitution of hatchery eggs for consumed eggs. If this is so, the curve D_cD_c is relatively steep. In such cases, most of the eggs collected for hatcheries will come from extra eggs taken from the wild rather than from eggs diverted from human consumption. In such circumstances, the argument loses force that hatcheries help sustain turtle populations because they utilize eggs that would otherwise be consumed by humans. Furthermore, the claimed conservation benefits of hatcheries then depend heavily on their survival rates of hatchlings being higher than for offspring from naturally hatched eggs. It would, therefore, be of interest if the economic supply and demand curves shown in Figure 3 could be estimated empirically, but we do not have the data to do this yet.

There are two possible end-point cases involving the collection of turtle eggs. One involves situations in which no collection of eggs for human consumption occurs, and in the second case, all, or virtually all, eggs that are laid in the wild by sea turtles are collected for human consumption. In the former case, open-cycle turtle hatcheries can only be justified from a conservation viewpoint if they result in greater additions to populations of adult turtles than would occur in the wild. The second situation is illustrated in Figure 4, where X_3 is the quantity of eggs laid. There, the supply curve of harvested eggs is assumed to be SS. The demand for harvested eggs for human consumption is D_cD_c and is so high that market equilibrium is initially at E_1, with all eggs collected and consumed. Suppose now that hatcheries add to demand by the difference between D_TD_T and D_cD_c. A new market equilibrium is established at E_2. As a result, the consumption of turtle eggs is reduced to X_0.

Consequently, hatcheries save $X_3 - X_0$ of eggs from human consumption and the total collection of eggs remains constant at X_3. Therefore, if hatcheries have any success in ensuring that some of these eggs will result in turtle adults, they help stem declining turtle populations. However, this does not mean that hatcheries will necessarily be able to stem the decline in such populations.

The presence of hatcheries in these instances might result in a positive conservation outcome because all or nearly all eggs would otherwise be consumed by humans. In such instances, the conservation situation in the absence of hatcheries would be much worse for sea turtles. However, these circumstances should not be used as an excuse for lax management that results in few eggs collected for hatcheries producing adult turtles.

In this analysis, the eggs of all species of sea turtles are treated as homogenous. However, there could be differences in the prices of eggs depending on the rarity of species, taste preferences among consumers, and preferences of hatchery operators. For instance, the leatherback (*Dermochelys coriacea*) hatchlings are more difficult to raise in tanks even for a few days than some other species (Higgins 2003) and, therefore, are not normally reared in hatcheries. Hence, there is the possibility of egg selectivity by consumers as well as hatchery operators. However, these factors do not affect the general analysis.

Critical Ecological/Economic Condition to Be Satisfied If Hatcheries Are to Help Conserve Turtle Populations

A simple survival relationship can be used and combined with economic relationships to determine whether sea turtle hatcheries assist the conservation of

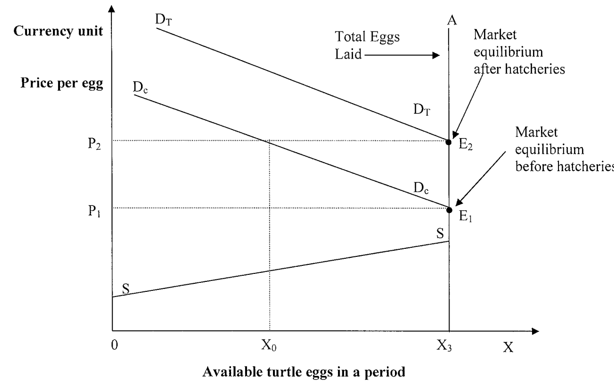

Figure 4. A case in which all turtle eggs are harvested and consumed prior to hatcheries entering the market, Market equilibrium for turtle eggs shown before (E_1) and after (E_2) the presence of hatcheries.

turtle populations or not. Let a_1 represent the proportion of turtle eggs that under ''natural'' conditions result in hatchlings entering the ocean and let a_2 represent this for turtle eggs used in hatcheries. Furthermore, let R represent the amount of eggs saved from human consumption by hatcheries (it corresponds to $X_1 - X_0$ in Figure 3) and let W represent the amount of extra eggs collected from the wild to satisfy hatchery needs (it corresponds to $X_2 - X_1$ in Figure 3).

Let S represent the difference arising from the presence of hatcheries in the number of turtle hatchlings entering the ocean (i.e., the difference compared to one in which no hatcheries exist). S is implicitly used as an indicator of the influence on the sea turtle populations of hatcheries compared to a situation where they do not exist. However, if hatchlings entering the ocean from hatcheries are weaker than those from the wild and, therefore, have less chance of surviving to become adults, the indicator should be adjusted to allow for this. To do this is straightforward in principle. Furthermore, note that the possibility of a change in sex ratios is ignored. The value of S can be estimated from the following expression:

$$S = R\boldsymbol{a}_2 + W(\boldsymbol{a}_2 - \boldsymbol{a}_1) \quad (1)$$

The term $R\mathbf{a}_2$ indicates the number of hatchlings surviving to enter the ocean from eggs buried by hatcheries. These eggs are no longer consumed by humans. The term $W(\mathbf{a}_2 - \mathbf{a}_1)$ specifies the difference in the number of hatchlings entering the ocean from eggs collected by hatcheries that otherwise would be left to their fate in the wild. In principle, R and W can be determined for the economic model outlined in the last section, and $\mathbf{a}_1$ and $\mathbf{a}_2$ are ecological parameters.

If $S = R\mathbf{a}_2 + W(\mathbf{a}_2 - a_1) > 0$, hatchery operations increase the number of turtles surviving to enter the ocean. On the other hand, this relationship can be negative if a_1 is larger than a_2. Hatcheries can then have a negative effect on the number of turtles surviving to reach the stage of ocean entry. If hatcheries are poorly managed, S could be conceivably negative, especially if the impact of hatcheries on the collection of extra turtle eggs for human consumption is low. There is also the possibility that $S = 0$, in which case, the presences of hatcheries has no impact on the survival of turtles to the ocean entry stage.

From the above discussion, it can be seen that the survival indicator for sea turtles headstarted through hatcheries is positive, zero, or negative:

$$S \gtreqless 0, \tag{2}$$

according to whether

$$Ra_2 \gtreqless - W(\mathbf{a}_2 - \mathbf{a}_1). \tag{3}$$

Therefore, if $R\mathbf{a}_2 > 0$ (i.e., some eggs go to hatcheries that would otherwise be consumed by humans and some of those result in hatchlings that survive0, then S can exceed zero, even if $\mathbf{a}_2 < \mathbf{a}_1$. However, other things equal, it is less likely to do so the smaller R (number of eggs saved from human consumption) is, the lower a_2 (the survival rate of hatchery ''headstarted'' turtles) is, and if $\mathbf{a}_2 < \mathbf{a}_1$, the greater is the number of eggs withdrawn by nurseries from the wild that would otherwise pass through a natural cycle.

Observe that if $R = 0$ (i.e., if hatcheries have no impact on human consumption of turtle eggs), $S \gtreqless 0$ according to whether $a_2 \gtreqless a_1$; the effectiveness of hatcheries in conserving sea turtle populations depends primarily on whether the survival rate of nursery started turtles exceeds than those in the wild. R may equal zero because the demand for turtle eggs for human consumption is perfectly inelastic or because there is no harvest of turtle eggs for human consumption. The latter could happen if, for instance, legislation banning the collection of turtle eggs for human consumption is completely effective. It might also happen because the demand of hatcheries for turtle eggs leads to a hike in the price, which forces consumers of turtle eggs out of the market. In Figure 3, this would involve a market price higher than any price along the line D_cD_c, but this is unlikely. Note that as R becomes smaller, the effectiveness of hatcheries in conserving turtle populations becomes increasingly dependent on hatcheries achieving higher survival rates for turtles than would occur from natural processes.

Basically, the above relationship boils down to the following: If hatcheries are adding to the burden of egg removal from the wild, they have to ensure that a greater percentage of turtles survive from the eggs they use than would occur in the wild. This result will depend on the combination of hatching rates that they achieve and the survival rate of their hatchlings. Only when it is know that the survival of turtles from hatchery eggs is higher than in the wild (and the hatchlings produced by hatcheries will successfully complete their life cycle) can we be confident that hatcheries are an effective conservation tool. Potentially, survival rates achievable by hatcheries are likely to be higher than in the wild. However, if hatcheries are poorly managed, they could be lower.

Two effects are likely to occur with rising tourist demand for visits to turtle hatcheries: (1) The operation of hatcheries becomes more profitable and this is likely to encourage additional enterprises to enter the industry and (2) the demand of existing hatcheries for eggs is at least likely to maintained or might be expanded. The latter is evident in Sri Lanka. Consequently, fewer eggs are usually available for human consumption and, above all, fewer and fewer turtle eggs are left in the wild. In such situations, most turtle eggs have to rely on hatcheries for incubation, and turtle hatchlings also become hatchery dependent. In those circumstances, the standard of management of the hatcheries becomes crucial for the survival of sea turtles. Whether or not private individuals who run these hatcheries in developing countries are in a position to maintain appropriate management standards is unclear. In principle, at least, greater public regulation of standards is desirable.

Impacts of Turtle Hatcheries on Total Economic Value: Static and Dynamic Considerations

Economists now increasingly stress the importance of assessing the economic value of environmental resources in terms of their total economic value (Freeman 2003, Chap. 5). Normally, total economic value is divided into use value and nonuse value. In turn, use value is subdivided, as a rule, into consumptive use value and nonconsumptive use value.

In the case of sea turtles, consumptive use value is the economic value obtained when turtle eggs, meat, shells, and so on are consumed. Nonconsumptive economic use value is obtained when turtles are used merely for viewing by tourists. Nonconsumptive use is usually regarded as a more benign form of economic use than consumptive use. However, nonconsumptive use might have negative impacts on turtle populations if behavior by tourists interferes with the reproduction of turtles or if the turtles are held in captivity for tourism or in hatcheries that are poorly managed. When such negative effects on turtle populations occur, tourism activities can be regarded, to some extent, as consumptive and the dichotomous consumptive/nonconsumptive classification frequently used in the relevant literature does not strictly hold.

Nonuse value consists of values such as existence value, bequest value, and, in some classifications, option values. The existence value of species of turtles depend on the satisfaction that individuals obtain from merely knowing that these species continue to exist. It might rise as the probability of these species surviving increases. Bequest value refers to the satisfaction that some individuals obtain from knowing that species (e.g., of turtles) will be available for future generations to enjoy.

Let us in turn consider the likely impacts on total economic value of three possible scenarios involving turtle hatcheries. In turn, consider the following situations: (i) Hatcheries have zero impact on the population levels of adult turtles, (ii) reduce their population, and (iii) increase their population.

If hatcheries have a neutral (zero) impact on turtle populations, they do not alter the nonuse value of sea turtles. However, hatcheries increase the nonconsumptive use value (economic benefit) of turtles for tourism. However, at the same time, in the normal case, the gathering of eggs for hatcheries will increase the price of turtle eggs and reduce the consumers' surplus of those eating turtle eggs. However, the gain in economic surplus by gatherers of turtle eggs as a result of a rise in their price brought about by the presence of hatcheries exceeds the economic loss to consumers of eggs. Furthermore, tourists and hatcheries have economic gains. Thus, standard economic theory, in a static setting, would indicate an increase in aggregate economic gain (compare Clarke and Ng 1993) as a result of the presence of turtle hatcheries even though, as pointed out by Tisdell (2000, pp. xx–xxiii), this needs qualification.

The consequences for aggregate economic welfare when hatcheries have a neutral impact on the population of sea turtles can be illustrated in Figure 5 for consumers of turtle eggs and gatherers of turtle eggs. Observe that the neutrality effect will be present in the short run, but that is more problematic whether it would occur in the long run. Figure 5 depicts the same type of situation as illustrated in Figure 3. In Figure 5, E_1 represents the market equilibrium for turtle eggs prior to the establishment of hatcheries and E_2 is that equilibrium after hatcheries have been established. As

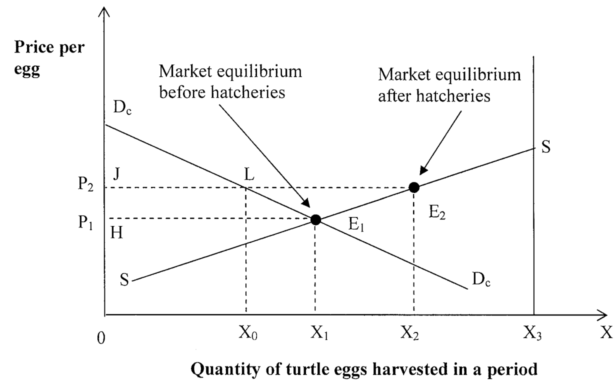

Figure 5. Illustration of a case where turtle hatcheries have a neutral impact on turtle populations and raise aggregate economic welfare (see text).

a result, the market equilibrium price of turtle eggs rises from P_1 to P_2. Consequently, those who purchase and eat turtle eggs suffer a loss in consumers' surplus of an amount equal to the area of quadrilateral HE_1LJ. On the other hand, the economic surplus of gatherers of turtle eggs rises by the equivalent of the area of quadrilateral HE_1E_2J. Therefore, there is a net increase in aggregate economic welfare of these stakeholders (if the Kaldor–Hicks or potential Paretian improvement criterion is adopted) of an amount equal to the area of triangle E_1E_2L.

In addition, after the establishment of hatcheries, one would expect those visiting hatcheries to obtain an extra economic surplus and also the operators of hatcheries to have a surplus that would not otherwise be available to them in the absence of hatcheries. Hence, taking into account the four stakeholders who obtain use value in this case, their net aggregate economic surplus rises. In addition, one would expect nonuse values to remain constant unless nonusers of hatcheries object to the *ex situ* (non-natural) means used by hatcheries to help reproduce turtles. If so, there would be a negative nonuse externality generated that would reduce nonuse value and complicate the situation. A similar type of analysis can be applied to the two cases outlined next.

If, on the other hand, hatcheries have a negative impact in the long run on populations of turtles, an aggregate economic loss might emerge. As the populations of turtles decline, their nonuse values can be expected to decline and the cost of harvesting turtle eggs will usually rise in due course. As a result of the latter, the supply curve of harvested eggs moves upward (see Figure 3). Both the consumers' surplus obtained by consumers of eggs and the economic surplus obtained by egg-gatherers can fall as a result. This might be accompanied by declining stock of eggs for hatcheries. Consequently, benefits to hatcheries and to tourists might decline. The aggregate economic value could decline in all respects. In the worst case, egg supplies could dry up, with no sustainable economic value remaining at all.

In the most favorable situation, hatcheries would add to populations of wild turtles in the long run, and the cost of harvesting eggs would fall. All components of total economic value could then begin to rise; that is, both types of economic use values increase and nonuse value as well. However, it is by no means certain that hatcheries are having this ''win–win'' result.

Discussion and Concluding Comments

Most species of sea turtles are claimed to be critically endangered or to be endangered and various policies including temporary protection and ''headstarting'' intervention by hatcheries have been adopted with a view to halting or reversing the decline in their populations. In Sri Lanka, most hatcheries have arisen from private initiatives to take advantage of the tourist trade. Hatchery operators are often motivated by a mix of commercial and conservation aims.

In Sri Lanka, hatcheries are, strictly speaking, involved in illegal operations in their turtle-raising practices. However, because they have convinced the public and others that they make a positive contribution to the conservation of sea turtles, their presence is ''unofficially'' sanctioned and their collection of eggs is seen as ''justified.'' There are, consequently, few, if any, prosecutions for illegally collecting turtle eggs, although it is prohibited by law.

The effectiveness of hatcheries in halting or reversing declines in populations of wild sea turtles is unclear. Depending on the values of the survival variables identified in this article, the impact of turtle hatcheries on the numbers of turtle hatchlings entering the ocean might be positive or negative. The actual values need to be identified empirically and might vary between hatcheries and locations. Furthermore, as highlighted in this article, depending on the particular case, their impacts on the total economic value obtained from sea turtle species can be positive or negative. Given the increasing prevalence of sea turtle hatcheries in many developing countries, urgent consideration needs to be given to estimating the parameters in the relevant economic–ecological models in practical situations.

As ''ecotourism'' based on turtle hatcheries expands, the need to monitor the impacts of the hatcheries on adult populations of sea turtles grows because tourist expansion can be expected to increase the demand of hatcheries for sea turtle eggs. With expanding demand, as shown by the economic model used in the article, the proportion of remaining turtle eggs left to hatch in the wild might dwindle to insignificant proportions of the total clutches laid. In all of these situations, the survival of the populations of sea turtles depends almost completely on how ably hatcheries are managed. This situation is already apparent in some developing countries such as Sri Lanka. Unless appropriate management strategies are maintained by turtle hatcheries, they can do more harm than good for the conservation of sea turtles.

Apart from this, it is uncertain how effective ''headstarting'' programs of this nature are in increasing adult populations of targeted species (Frazer 1992). In addition, many conservationists have negative feelings about most sea turtles starting their lives in hatcheries rather than in the wild (Shanker and Pilcher 2003). Moreover, depending on hatchery conditions, sex ratios of turtles might be unfavorably altered by hatcheries (Tiwol and Cabanban 2000) and hatcheries could, in the long-term, favor the survival of strains less fit to survive in the wild.

Furthermore, tourism-based hatcheries that have profit maximization as an objective might be inclined to sacrifice conservation objectives to some extent. For instance, hatchlings emerging from buried nests are often not immediately released to the sea, but are kept in tanks, often for several days, to show tourists and to allow willing tourists to release hatchlings in return for a payment. Delaying the release of hatchlings to the ocean saves money for hatcheries because they do not have to purchase as many eggs to keep hatchlings on display for tourists. This can result in hatchlings being weak when released to the ocean and increase the likelihood of their injuring one another, thereby seriously reducing survival rates. Furthermore, holding ponds are often extremely small (to save money and space) and quite crowded, so adding to injuries of hatchlings.

Nevertheless, the above does not imply that hatcheries are unable to make a positive contribution to the conservation of sea turtles. In fact, they are recommended as a last resort where *in situ* conservation is not possible or impractical (cf. IUCN/SSC Marine Turtle Specialist Group 1999; IUCN 1995). This article underlines the point that both economic and ecological factors should be taken into account when assessing the impact of turtle hatcheries on turtle populations and that the impact can be either positive or negative.

This article is intended to counter the perception that turtle hatcheries inevitably make a positive contribution to the conservation of sea turtles and that their consequences for populations in the wild are bound to be positive. Furthermore, even when hatcheries make a positive contribution to the conservation of sea turtles, a scope might well exist for improving their performance in this regard. However, the commercial incentive for open-cycle hatcheries to achieve a high level of performance in conserving sea turtles might be weak if their main objective is to earn income from tourists. Because of asymmetry of information (the relatively poor knowledge of tourists of the conservation performance of hatcheries), the demand of ecotourists for visiting hatcheries is unlikely to be closely linked to the conservation performance of hatcheries. Again, such hatcheries only have *de facto* property rights in turtles for a part of their life cycle, and in some cases, this could weaken their conservation effort. On the other hand, operators of *profitable* closed-cycle turtle hatcheries have a strong incentive to maintain the level of their populations of turtles because turtles are the private property of the operators throughout their life cycle.

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