Herpetological Conservation and Biology 16(3):652–670.
Submitted: 14 January 2021; Accepted: 28 October 2021; Published: 16 December 2021.

Are Sea Turtle Hatcheries in India Following Best Practices?

Andrea D. Phillott[1,2,4], Nupur Kale[2], and Abhidnya Unhale[3]

[1]*FLAME University, Gat No. 1270, Lavale, Off Pune Bangalore Highway, Pune 412115, Maharashtra, India*
[2]*Dakshin Foundation, 1818, 9th Cross, 5th Main, Sahakar Nagar C block, Bangalore 560092, Karnataka, India*
[3]*N-3, Sankul near Dinanath Mangeshkar Hospital, Erandwane, Pune 411004, Maharashtra, India*
[4]*Corresponding author, e-mail: andrea.phillott@gmail.com*

Abstract.—**States and territories of India have long relocated sea turtle eggs to hatcheries for protection against threats including depredation and illegal take. We compared the practices of egg collection, transport, and incubation, and hatchling handling, holding, and release from 36 hatcheries with recognized best practices. Self-reported practices reflected some best practices, including replacing substrate annually and limiting nest density, but other practices, such as time interval between oviposition and reburial of eggs in the hatchery, were outside recommendations. Analysis of data sets showed that clutches incubated in hatcheries have comparable hatching success to unprotected *in situ* clutches when a higher hatching success would be expected with conservation effort. This finding, in combination with hatchlings being held after emergence and often in conditions that are likely to reduce fitness, indicates that some hatcheries may be limited in their potential effectiveness as an *ex situ* conservation strategy. Shading and/or watering nests to mitigate potentially high nest temperatures without monitoring temperature is also of concern, and we recommend the two be combined as a best practice. Hatchery personnel would benefit from regular opportunities to ensure ongoing understanding of sea turtle biology in relation to best hatchery practices and resources to ensure best practices can be implemented. Hatchling production would be better assessed by a permit (Non-Governmental Organizations and volunteer groups) and departmental (Forest Department) requirement for annual reporting of hatching and emergence success using accurate protocols. We also encourage that *in situ* protection of sea turtle eggs be considered in appropriate locations.**

Key Words.—conservation; egg; hatchery; hatching success; hatchling; nest; relocation

Introduction

Of the seven extant species of sea turtles, Green Turtles (*Chelonia mydas*), Leatherback Turtles (*Dermochelys coriacea*), Hawksbill Turtles (*Eretmochelys imbricata*), and Olive Ridley Turtles (*Lepidochelys olivacea*) nest in the states and territories of India. At all nesting beaches, adult sea turtles, eggs, and hatchlings face a myriad of biotic and abiotic threats. The most commonly described threats include depredation, habitat loss due to sand mining and beach armoring, light pollution, exploitation of eggs and potentially turtles, and inundation of beaches due to high tides, storm surges, and extreme rainfall events (reviewed by Shenoy et al. 2011; Phillott and Kale 2018; Manoharakrishnan and Swaminathan 2020). To safeguard populations in India, sea turtles are accorded legal protection under the Wildlife (Protection) Act, 1972. The most common conservation strategy for eggs and hatchlings is relocation of eggs to a protected incubation area known as a hatchery, located on, or adjacent to, the beach. Hatcheries are employed as an *ex situ* conservation strategy for vulnerable eggs in all coastal states and territories of India except for the Lakshadweep Islands. The majority of sea turtle eggs laid on nesting beaches in the states of Goa, Gujarat, Maharashtra, and Karnataka and on important nesting beaches, such as those on the Chennai coast in Tamil Nadu, are relocated to hatcheries (Phillott and Kale 2018). Hatchery practices and resultant hatchling production in India, therefore, have important implications for sea turtle recruitment dynamics and future population resilience (Dutton et al. 2005; Mazaris et al. 2009).

Protection of eggs in structures such as hatcheries has potentially contributed to successful conservation of some sea turtle populations worldwide (Mazaris et al. 2017); however, the efficacy of hatcheries has long been debated (Mrosovsky and Yntema 1980; Pritchard 1980; Mrosovsky 1983). Unless best practices in the collection, transport, and incubation of eggs, and holding and release of hatchlings are followed, relocation of clutches to hatcheries may result in lower hatchling production (Limpus et al. 1979; Eckert and Eckert 1990; Wyneken et al. 1998; Pintus et al. 2009; Revuelta et al. 2015) and/or fitness (Pilcher and Enderby 2001; Maulany et al. 2012b; Rusli et al. 2015), or skewed sex ratios (van de Merwe et al. 2005; Sieg et al. 2011; Maulany et al. 2012a; Revuelta et al. 2015; Sari and Kaska 2017)

Copyright © 2021. Andrea D. Phillott
All Rights Reserved.

compared to undisturbed clutches left *in situ*. Resources describing best practices for sea turtle hatcheries are widely available to sea turtle conservationists in India in several forms (Mortimer 1999; Shenoy et al. 2011; Phillott and Shanker 2018) and some hatcheries have conducted self-assessments to examine their practices and hatchling production, fitness, and/or sex ratios (Abd Mutalib and Fadzly 2015; Revuelta et al. 2015; Sari and Kaska 2017).

Due to the high risks and costs involved in *ex situ* conservation interventions, it is important to examine if conservation strategies follow best practices to achieve their objectives (Pullin and Knight 2001; Sutherland et al. 2004, 2009). For sea turtle hatcheries, this would include the metrics of equivalent or higher hatchling production and hatchling fitness and similar sex ratios in comparison to that of *in situ* nests remaining on beaches from which threatened eggs have been relocated. Annual average hatching success (the proportion of eggs producing hatchlings that hatch from their eggshell) and/or emergence success (the proportion of eggs producing hatchlings that reach the beach surface; Miller 1999) are the easiest and cheapest metrics to assess. Such data, however, may not be available if all, or the majority, of known nests are relocated to hatcheries or *in situ* nests are rarely monitored; either or both such situations occur on most sea turtle nesting beaches in India. Therefore, we separately compared primary data on current sea turtle hatchery practices in India with recommended practices for collecting, handling, and incubating turtle eggs, and housing and releasing hatchlings to assess if hatcheries are following best practices and secondary data on hatchling production from hatcheries and *in situ* nests within the region to determine if hatchling productivity is enabling hatcheries in India to meet conservation objectives.

Materials and Methods

Hatchery purpose, management, and practices.—We used a non-experimental, descriptive, cross-sectional study design (Margoluis et al. 2009; Newing et al. 2011) to draw inferences about the practices of hatcheries in India, as potential issues relating to accuracy and bias in participant responses precluded an analytical approach. Purposive sampling to recruit potential study participants was guided by a published review of primary and technical literature on sea turtle hatcheries in Indian states and territories (Phillott and Kale 2018), which identified the potential locations of current hatcheries, and inquiries among our personal contacts for the names of current hatchery personnel. We invited hatchery owners, managers, or other senior personnel to participate in online questionnaires or face to face interviews from December 2015 to June 2018. Following the International Sociological Association Code of Ethics for Research Procedures (https://www.isa-sociology.org/en/about-isa/code-of-ethics), prior informed consent that potential participants understood the study purpose, content, and planned dissemination of findings was ensured either verbally (face to face interviews; written consent is not common in India) or in writing (online questionnaires). We notified potential participants that responses would be confidential and that they could decline to answer any questions or further questions at any time. We offered no compensation in return for participation.

We delivered online questionnaires in English and face to face interviews in Hindi, Kannada, or Marathi according to the preference of the participant. We collected responses to 20 closed and open-ended questions (see Appendix Questionnaire) about hatchery operations, characteristics, and hatchling production; questionnaires and interviews alike required 30–60 min to complete. Responses were anonymized and given an identification code comprising a state prefix and sequential letter. We then summarized hatchery practices by state. We calculated the mean ± 1 standard deviation (SD) and range for hatchery practices with numerical responses (e.g., number of source beaches, hatching success, etc.). If participants provided a range in their response to a quantitative question, we used the median value of the range to calculate mean and standard deviation while the highest and lowest values in the range were used to estimate minimum and maximum. The study design was based on the likely sample size and potential for response bias, and therefore, allowed for limited calculation of inferential statistics that compared data sets or examined relationships among variables. We used a Shapiro-Wilk Test of Normality to assess the distribution of data sets, which were not normally distributed, so we used a non-parametric Kruskal-Wallis test. We compared self-reported hatchery practices against accepted best practices (Tables 1, 2). To ensure confidentiality for participants describing practices that could reduce hatching success or hatchling fitness and survival, we minimized the use of personal anecdotes shared during the study and instead examined the literature about hatcheries in India for published descriptions of similar practices to use as examples.

Hatchling production.—We asked participants about the mean average hatching success at their hatchery but recognized the potential for response bias. Given the challenges in obtaining unpublished raw data from hatchery managers, we also assessed the hatchling production of hatcheries in India as described in primary literature and online reports including detailed data (e.g., number of eggs laid and hatchlings emerged from eggs; Appendix Table 1). We compared data with the

Table 1. Best practices for hatchery management and records. (Adapted from Phillott and Shanker 2018).

Best Practice and Justification		Supporting Literature
Personnel	• Train employees and volunteers in sea turtle biology, conservation, and hatchery management techniques. • Provide access to general articles and manuals about sea turtle biology and hatchery practices.	Shenoy et al. 2011
Hatchery records	• Record information including date of oviposition, clutch size, date of emergence, number of hatchlings, and (if possible) weight and carapace length.	Mortimer 1999; Schäuble et al. 2002; Shenoy et al. 2011
Monitoring and evaluation	• Calculate incubation period as a number of days between oviposition and emergence. • Excavate nest 2–3 days after the majority of hatchlings have emerged and calculate: a) Hatching Success = (Number of hatched eggs/Total number of eggs) × 100 b) Emergence Success = (Number of naturally emerged hatchlings/Total number of eggs) × 100 • Monitor nest temperature and hatchling sex ratio from a statistically valid proportion of nests in hatchery and compare with data from the natural beach/es for your population of sea turtles.	Mortimer 1999; Schäuble et al. 2002; Shenoy et al. 2011

hatching success of clutches incubated in *in situ* nests from India and other countries in the northern Indian Ocean, as estimates of hatching success from *in situ* nests in India, and in hatcheries from other countries in the northern Indian Ocean (Appendix Table 1). Before we used a Shapiro-Wilk Test of Normality to assess distribution, we converted percentile data in each set to arcsine values. We used a non-parametric Kruskal-Wallis test to compare the hatching success among the three independent samples. All inferential statistics were calculated in IBM SPSS Statistics v25 (IBM Corp, Armonk, New York, USA), with $\alpha = 0.05$.

Results

In total, 34 participants from 36 hatcheries in the states of Andhra Pradesh (n = 2), Goa (n = 3), Gujarat (n = 6), Karnataka (n = 2), Kerala (n = 2), Maharashtra (n = 16), Odisha (n = 3), and Tamil Nadu (n = 2; Fig. 1) agreed to be interviewed about their hatchery practices. Responses were obtained from > 90% of those from Goa, Gujarat, Maharashtra, and Odisha who were invited to contribute to the study. We were unable to obtain information about the total number of hatcheries managed by the state Forest Department or Non-

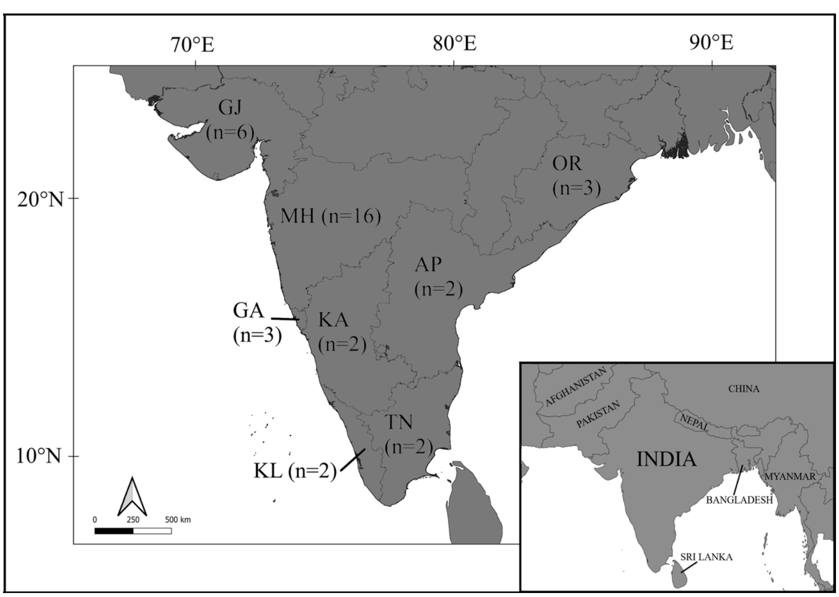

Figure 1. Distribution of sea turtle hatcheries among eight states in India (inset map) that contributed to the study. States abbreviations are AP = Andhra Pradesh, GA = Goa, GJ = Gujarat, KA = Karnataka, KL = Kerala, MH = Maharashtra, OR = Odisha, and TN = Tamil Nadu.

Table 2. Best practices for handling and incubating eggs and handling and releasing hatchlings in sea turtle hatcheries. (Adapted from Phillott and Shanker 2018).

Best Practice and Justification		Supporting Literature
Hatchery location and construction	• Provide a diversity of nest microhabitats (e.g., shade, slope) to reflect conditions on the nesting beach and avoid potentially skewing sex ratios of hatchlings. • Change location of hatchery every year to avoid accumulation of organic material and high microbial load.	Mortimer 1999; Spanier 2010; Shenoy et al. 2011; Maulany et al. 2012a,b
Egg handling and transport	• Transport eggs in rigid containers to minimize rolling and potential embryo mortality. • Maintain eggs in original orientation, without vertical or horizontal rotation, if transporting more than 3 h after oviposition. • Rebury eggs in hatchery within 3 h (preferable) to 6 h (maximum) of oviposition to minimize embryo mortality. • Use low-temperature or hypoxic environments to maintain embryo viability if eggs require long distance and/or long travel.	Limpus et al. 1979; Parmenter 1980; Harry and Limpus 1989; Williamson et al. 2017
Incubation conditions	• Rebury eggs in a hatchery nest as deep as that of the natural nest. • Rebury eggs in a hatchery nest with a shape that reflects that of the natural nest (usually flask shaped with a narrower neck than base). • Maintain a density of no more than 1 nest/m^2 to minimize the effects of adjacent nests on temperature and respiratory gas availability. • Place eggs individually into the nest; do not 'pour' eggs from a bucket or bag. • Use moist sand removed during nest construction to cover eggs as exposure of eggs to dry sand introduces risk of desiccation. • Incubate all eggs from a single clutch in the same hatchery nest; do not split/divide clutches between hatchery nests or combine clutches from different nests. • Minimise risk of lethal nest temperatures, especially late in incubation, through partial shading of the hatchery. Monitor nest temperatures to avoid skewing hatchling sex ratios from natural.	Mortimer 1999; van de Merwe et al. 2005; Maulany et al. 2012a,b; Rusli and Booth 2016
Nest enclosures	• Mark and label individual nests for monitoring. • Cage individual nests with enclosures of rigid material- not metal wire- about 60 cm in diameter to reduce depredation and energy of expenditure by hatchlings crawling throughout hatchery.	Mortimer 1999; Shenoy et al. 2011
Hatching release	• Predict emergence date, often 45-55 d after oviposition. The characteristic 'caving in' of sand above the nest indicates emergence will usually begin within 2–3 d. • Check enclosures every 30–60 min from afternoon to dawn and at other times when hatchlings may emerge (e.g., on overcast days and after rain) around the predicted emergence date. • Release hatchlings as soon as possible to prevent exhaustion, desiccation, loss of vigor, possible injury, or death from predators. • Release hatchlings in groups, if possible, to improve survival probability; however, early emergers should not be held until more hatchlings emerge as this practice can result in loss of vigor. • Randomize clutch release sites hundreds of meters apart to avoid creating fish feeding stations off the beach, which increases the risk of predation. • Allow hatchlings to crawl from the dune across the beach and enter the ocean unassisted to facilitate imprinting. • Manage observers to ensure hatchlings are not injured or their progress to the sea impeded; parallel lines about 20 m apart on the beach give a mark for people to stand behind while hatchlings crawl between lines. • Ensure artificial lights are shielded during hatchling emergence and release, and after they enter the ocean to minimize disorientation. • Hold hatchlings that emerge in heat of day or when immediate release is not possible in a cool, dark place. Do not hold hatchlings in water as they will enter their 'swim frenzy' period and deplete energy reserves needed for survival and dispersal.	Mortimer 1999; Wyneken 2000; Pilcher and Enderby 2001; Shenoy et al. 2011; van de Merwe et al. 2013

Governmental Organizations (NGOs) in Karnataka, Kerala, or Tamil Nadu, determine if any hatcheries still operated in West Bengal, or acquire information about known hatcheries in the Andaman and Nicobar Islands.

Hatchery purpose.—Participants described that all hatcheries except one (97%) were needed to protect eggs against predators; the exception functioned solely for research. Many hatcheries had more than one purpose, with the second most common being protection of eggs against illegal take (36%). Few hatcheries engaged in ecotourism or education (25%; Appendix Table 2).

Hatchery management.—Most hatcheries were managed solely by the Forest Department of the state (61%) or an NGO/volunteer group (22%); in only six cases (17%) did two managing bodies jointly oversee the same hatchery. The years of operation ranged from 2 to 28. All hatcheries employed staff, usually between 1–6 persons but two hatcheries in Maharashtra compensated up to 50 members of local families to help monitor beaches and collect eggs. Hatcheries managed by an organization other than a state Forest Department held a required permit (Appendix Table 2).

Hatchery practices.—Most hatchery personnel had received training in best practices for hatchery operations, but few hatcheries referred to formal, published guidelines. Few respondents to our survey named the workshop facilitators or guidelines as requested, but those who did described training by the NGO Dakshin Foundation (or members of its Turtle Action Group [TAG] 2011) and referenced a field guide published by the same NGO (Shenoy et al. 2011). Records were maintained for annual numbers of clutches/eggs and hatchlings to be reported to the respective state Forest Department by all hatcheries, including those operated by the state Forest Department itself (Appendix Table 2).

All hatcheries in Gujarat were permanent structures, comprising a concrete footing and/or frame covered with wire mesh or fishing nets, which had remained in place over successive years (mean longevity = 10 ± 9 y; range, 3–25 y) with the sand substrate replaced annually. All hatcheries in all other states were temporary structures (Appendix Table 2), constructed at the beginning of each nesting season and removed when all hatchlings had emerged. Such hatcheries were constructed using a bamboo or wooden frame covered with cloth, fishing net, mosquito net, or plastic fencing material, and their location varied annually with beach topography and nesting density.

Olive Ridley Turtle eggs were the only eggs incubated at hatcheries in every state except Gujarat, at which Green Turtle clutches were predominant with only occasional clutches of Olive Ridley Turtle eggs reported to be incubated at one hatchery. The annual number of clutches incubated varied substantially (range, 1–300) among hatcheries within and among the states. Hatchery personnel were usually responsible for collecting and relocating eggs to the hatchery; only 11% of hatcheries procured eggs from independent egg collectors with compensation ranging from INR ₹10 or 15 per egg (about USD $0.13–0.20) or INR ₹600 or ₹5,000 per clutch (about USD $8.01 or $66.78). Eggs were collected from the beach at which the hatchery was located and/or adjacent beaches up to 78 km away, and transported by foot, motorbike, or bicycle in a rigid container (plastic bucket, coir basket, or styrofoam box) or flexible bag (cloth or plastic) from the source beach to the hatchery (Appendix Table 2).

The relocation interval, between when eggs were laid and buried in the hatchery, was < 3 h in only 32% of all hatcheries and < 6 h in 73% of all hatcheries (Appendix Table 2). The number of beaches from which eggs were collected deviated significantly from normal for time intervals of < 3 h (W = 0 .763, df = 9, P = 0.008), 3–6 h (W = 0.851, df = 14, P = 0.023) and > 6 h (W = 0.772, df = 13, P = 0.003). Relocation intervals increased significantly with the number of beaches from which hatcheries sourced eggs (H = 12.55, df = 2, P = 0.002). The distance traveled deviated significantly from normal for clutches relocated in all time intervals: < 3 h (W = 0.482, df = 9, P = 0.000), 3–6 h (W = 0.819, df = 14, P = 0.009) and > 6 h (W = 0.301, df = 12, P = 0.010). There was no significant difference in transport distance among relocation intervals (H = 2.08, df = 2, P = 0.353); instead, respondents attributed longer relocation times to delays in the period between oviposition and egg collection before reburial in the hatchery. Some hatcheries only collected eggs laid the previous night after 0800 or moved eggs to a hatchery after checking beaches for turtle nesting only once a week.

Despite all hatcheries incubating predominantly Olive Ridley Turtle eggs, nest depths varied among states. Most hatcheries in Maharashtra (91%), Odisha (100%) and Tamil Nadu (100%) incubated eggs at a depth that approximated that for Olive Ridley Turtles (41 ± 7.0 cm; range, 33–50; Rashid and Islam 2006), but nest depths were shallower in some clutches transferred to hatcheries in Goa (67%), Karnataka (50%), and Kerala (50%), and deeper in some clutches incubated at hatcheries in Goa (33%), and all clutches in Gujarat (100%; Appendix Table 2). Nest density was < 1/m^2 in the majority of hatcheries in all states except Karnataka (0%). Nest temperatures were monitored in 31% of all hatcheries. Mitigation measures for high temperatures consisted of shading the hatchery (using coconut and/or palm leaves in Andhra Pradesh and Goa, plastic roofing in Gujarat, and gunny bags or jute fabric in Karnataka and Tamil Nadu) or watering nests and were used in 22% and 11% of hatcheries respectively (Appendix Table 2).

All hatcheries, except for five in Maharashtra, marked and labeled nests that would facilitate monitoring for hatchling emergence. Caging nests to quantify hatchling production for each nest was practiced less frequently across states. Hatchlings were released within 30 min (considered immediately) by only 44% of hatcheries. The remaining hatcheries held hatchlings for hours (44%) to days (8%) or months (3%). Hatchlings were housed in water by 42% of hatcheries, before release within 30 min of emergence (one hatchery in Gujarat), or after being held for hours, days or months. Hatchling releases were viewed by the public or invited guests infrequently among all hatcheries (29%), but at 50% or more of all hatcheries in Karnataka, Kerala and Tamil Nadu (Appendix Table 2).

Comparison with best practices.—The proportion of hatcheries following best practices varied among and within states. Staff training occurred in all hatcheries within each state except Goa (0%) and Maharashtra (69%) but maintenance of records for reporting purposes was universal (100%). Hatchery structure was always appropriate (100%; Table 3).

Transport of eggs to hatcheries in rigid containers was less common in Kerala (50%), Maharashtra (69%), Odisha, and Tamil Nadu (0% each). Relocation of eggs to the hatchery within 6 h of oviposition occurred in 74% of all hatcheries: 100% of hatcheries in Goa, Karnataka, Odisha, and Tamil Nadu, and at least 50% of hatcheries in Kerala and Maharashtra. Only one of the six hatcheries in Gujarat and four of the 16 hatcheries in Maharashtra responded to this question, however. Best practices for incubation conditions (nest density and depth) were met by all hatcheries in Andhra Pradesh, Odisha, and Tamil Nadu, and ≥ 50% of hatcheries in Kerala and Maharashtra. Of those hatcheries that did use shading or watering to mitigate nest temperatures, only 56% also monitored nest temperatures. Hatcheries frequently followed recommendations for nest density (74%), nest depth (71%), and marking and labeling (86%), but less frequently when caging nests (57%) to help calculate hatchling emergence (Table 3). Recommendations for holding and release of hatchlings were followed by all hatcheries in Andhra Pradesh, and ≥ 50% of hatcheries in Goa and Maharashtra, but not other states.

Hatchling production.—Participants in our study reported hatching success to average about 75% ranging from 40–90% (Appendix Table 2); however, only 57% of nests (Table 3) were caged, and some participants

Table 3. Percentage of sea turtle hatcheries in each state of India meeting best practices as described in this study. States abbreviations are AP = Andhra Pradesh, GA = Goa, GJ = Gujarat, KA = Karnataka, KL = Kerala, MH = Maharashtra, OR = Odisha, and TN = Tamil Nadu. Superscripts are [1]Participants from only four of 16 hatcheries in Maharashtra responded to this question; [2]Participant from only one of two hatcheries in Kerala responded to this question; and [3]Participants from only 15 of 16 hatcheries in Maharashtra responded to this question.

	State (number of hatcheries)							
Practice	AP (n = 2)	GA (n = 3)	GJ (n = 6)	KA (n = 2)	KL (n = 2)	MH (n = 16)	OR (n = 3)	TN (n = 2)
Staff training	100	0	100	100	100	69	100	100
Records maintained	100	100	100	100	100	100	100	100
Hatchery structure- temporary or sand replaced annually in permanent structure	100	100	100	100	100	100	100	100
Egg transport container	100	100	100	50	100	69	0	0
Relocation time[1]								
< 3 h	0	67	0	0	50	25	33	50
3–6 h	0	33	0	100	50	25	67	50
Nest density[2]	100	100	100	0	100	75	100	100
Nest depth	100	0	0	50	50	91	100	100
Combined temperature mitigation with monitoring	100	0	33	0	n/a	n/a	n/a	100
Marking and labelling nests	100	100	100	100	100	69	100	100
Caging nests[3]	100	67	100	0	50	25	100	100
Hatchling release time	100	67	33	0	0	71	0	0
Hatchling holding conditions	100	67	50	50	50	64	33	50

disclosed that accurate records of the number of eggs incubated and successfully hatched were not kept; instead, hatching success was only estimated from the number of hatchlings found in the hatchery. Further, we suspect response bias during our survey, in which some participants indicated a hatching success they believed that we would find more favorable or that would more positively portray their hatchery operations. Unpublished short-term raw data sets shared with us during the study allowed an average hatching success of 55% at one location and 69% at another; respondents from the hatcheries described the hatching success of their hatchery to be 60–70% at both locations. Hence, the hatching success reported by participants allow a comparison for the purpose of this study but are not appropriate for inclusion in a future meta-analysis.

Hatching success of clutches incubated *in situ* (n = 14) throughout the region (mean = 76% ± 11; range, 44–87) was higher than that of clutches incubated in hatcheries (n = 10) in India (67% ± 21; range, 21–95) and in other countries in the northern Indian Ocean (59% ± 28; range, 26–92; Appendix Table 1). Hatching success of clutches incubated *in situ* in the region (W = 0.911, df = 14, P = 0.165) and in hatcheries in India (W = 0.950, df = 10, P = 0.670) and elsewhere in the northern Indian Ocean (W = 0.918, df = 6, P = 0.493) did not deviate significantly from normal. Hatching success did not differ significantly among the three groups (H = 1.564, df = 2, P = 0.457).

Discussion

We assessed the practices of 36 hatcheries in India, some of which had not been previously documented by Phillott and Kale (2018). The number of hatcheries and their longevity can vary over time within a state or district (Phillott and Kale 2018), but respondents to our survey represent most hatcheries known to be currently operating in Goa, Gujarat, Maharashtra, and Odisha and a lesser proportion of hatcheries in Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu. Hence, there is the potential for non-response bias in our assessment of hatchery practices in the latter four states.

We argue that the presence and practices of hatcheries incubating smaller numbers of clutches in the western states of Goa, Gujarat, Karnataka, Kerala, and Maharashtra are as important as those of larger hatcheries in the eastern states of Odisha and Tamil Nadu. Clutches relocated to hatcheries on the west coast of India represent a large proportion of the total clutches laid annually in each state and contribute hatchlings to potentially different ecological populations (Shanker et al. 2011. Conservation genetics of marine turtles on the mainland coast of India and offshore islands. Wildlife Institute of India, Dehradun, and Centre for Cellular and Molecular Biology, Hyderabad, India. Available from https://kslab.weebly.com/reports.html [Accessed 11 January 2021]) if not different Regional Management Units (RMUs; see Wallace et al. 2010) than clutches protected by hatcheries operating on the east coast of India. Therefore, the impact of practices by an individual hatchery on sea turtle populations of India cannot only be determined by the number of clutches it protects annually.

Hatchery purpose.—The primary goal of 97% of hatcheries we surveyed was to protect sea turtle eggs from depredation and illegal take, both commonly cited as threats to sea turtle eggs in India and reasons for establishing hatcheries (Tripathy and Rajasekhar 2009; Behera et al. 2013; Phillott and Kale 2018). Despite the take of sea turtle eggs being illegal in India under the Wildlife (Protection) Act of 1972, 50% or more of hatcheries in Andhra Pradesh, Goa, Kerala, and Tamil Nadu perceived it as an ongoing threat to sea turtles. While the perception is possibly subject to over-estimation by local sea turtle researchers and conservationists (Kartik Shanker, pers. comm.), the frequency of the response indicates a need to accurately quantify illegal take of eggs and identify the potential drivers, including socioeconomic needs, cultural practices and/or low legal enforcement, to understand and effectively mitigate the threat if required.

Few hatcheries identified ecotourism as a purpose for their hatchery. The potential for hatcheries to generate income for local communities through tourism could be an incentive to reduce illegal take, and Kale et al. (2016) identified the factors likely to contribute to the success of such ventures through their case studies of the Velas Turtle Festival (Maharashtra) and initiatives in Goa. Hatchling releases at some hatcheries in Karnataka, Kerala, Tamil Nadu, and Maharashtra (an example from Kerala is described in Sundaram et al. 2020) were observed by local community members and/or Forest Department officials. In addition to protecting eggs and hatchlings, hatcheries can play an important role in raising community education and awareness about the biology of and threats to sea turtles (as demonstrated in India by Arun 2019; Sundaram et al. 2020) through hatching releases and volunteer opportunities, and this appears to be under-used potential of many hatcheries that could be strengthened with further resources.

Hatchery management.—Despite the intense work of monitoring nesting beaches, collecting and reburying eggs, releasing hatchlings, and maintaining egg incubation enclosures, hatcheries in India employed relatively few staff (the exception were two hatcheries in Maharashtra). Compensated staff and community members and volunteers contribute greatly to the operations of some hatcheries, especially the Students' Sea Turtle Conservation Network based in Chennai, Tamil Nadu (Shanker 2015), and volunteer practices likely reflect those developed by staff during their training. Hatching success of eggs moved to hatcheries can vary with the identity and practices of those responsible (Almeida and Mendes 2007), so an assessment of the collection, handling, and movement of eggs by independent collectors and outcomes of incubation would complement the findings of the current study.

Hatchery practices and potential implications.—The number of sea turtle clutches incubated in hatcheries as reported to us in the current survey, especially in Andhra Pradesh, Gujarat, and Kerala, was often lower in comparison to previous records (Phillott and Kale 2018), potentially indicating a decline in number of nesting turtles. The number and name of source beaches for eggs was often not included in previous publications and reports, so it is challenging to determine if hatcheries in Andhra Pradesh, Gujarat, and Karnataka, where the average number of source beaches for eggs is greater than two, are now collecting eggs from a greater number of beaches than historically. A greater number of source beaches could indicate (1) lower numbers of nesting turtles and hatchery staff traveling further afield to collect eggs and maintain their existence; (2) be an artefact of a reduced number of hatcheries currently operating and staff needing to protect eggs from a longer stretch of coastline; or (3) represent expansion of sea turtle conservation activities. Whatever the reason, the number of beaches from which eggs are collected may have implications for the relocation interval and subsequent embryo mortality and hatchling production (see below). Similarly, transport of eggs in flexible, and not rigid, containers may also reduce hatching success by an unknown mechanism (Maulany et al. 2012b).

The relocation interval is often not within the preferred (< 3 h) or maximum (< 6 h) period. The time interval between oviposition and reburial of eggs could be a function of multiple factors, including the number of source beaches from which eggs are collected, number of personnel available to monitor nesting beaches, and frequency at which nesting beaches are monitored, but did not vary with distance between the nesting beach and the hatchery. As hatcheries in India have low human resources, and potentially low human capital, and often source eggs from multiple beaches (up to 14), it is not surprising that the relocation interval exceeds that recommended in nearly all of the hatcheries we surveyed. Movement of eggs after 6 h post-oviposition results in significantly greater embryo mortality rates (Limpus et al. 1979; Parmenter 1980) as extraembryonic membranes that adhere to the shell membrane soon after oviposition (Blanck and Sawyer 1981) are likely damaged and will contribute to lower hatchling production. Increasing the number of hatcheries to reduce the number of source beaches would potentially reduce relocation interval but will again require greater resources.

Incubation conditions at hatcheries in India (e.g., nest density and depth) are often, but not always, within those recommended. Hatcheries that incubate clutches at a greater density than 1/m^2 (for an example, see Behera et al. 2013) risk reducing available oxygen and elevating levels of carbon dioxide and incubation temperature, and potentially reducing hatching success (Honarvar et al. 2008). Eggs from comparatively shallow nests are more likely to be exposed to the upper lethal temperature limit of sea turtle embryos (Table 4), while deeper than average nests can increase energy expenditure during prolonged hatchling digging and potentially reduce emergence

Table 4. The influence of nest temperature on Olive Ridley Turtle (*Lepidochelys olivacea*) embryos and hatchlings. Regional examples provided where possible.

Parameter	Known Information	Study Location (Source)
Upper Lethal Temperature or Limit- upper temperature of thermal tolerance range above which embryo development is impaired (Ackerman 1997)	Hatching success decreased when mean nest temperature > 35° C, or decreased with days of nest temperatures > 35° C when mean < 35° C	Ostional, Costa Rica (Valverde et al. 2010)
Pivotal Temperature- incubation temperature that results in 50% female and 50% male hatchlings (Mrosovsky and Yntema 1980; Yntema and Mrosovsky 1982)	About 29.5° C	Gahirmatha, India (Mohanty-Hejmadi et al. 1985, Mohanty-Hejmadi and Dimond 1986)
Transitional Range of Temperatures- range of temperatures that produces both sexes (Mrosovsky and Pieau 1991)	Within 28°–30° C	Gahirmatha, India (Mohanty-Hejmadi et al. 1985)
Thermosensitive Period- time interval of incubation during which temperature affects sexual differentiation of the gonads (Mrosovsky and Pieau 1991)	Occurs in the second third (or trimester) of embryo development	La Escobilla, Mexico (Merchant-Larios et al. 1997)
Hatchling Fitness- measurable features (phenotypes, traits) that predict their survival and likely contribution to future generation (Hunt and Hodgson 2010)	Higher nest temperatures have implications for hatchling morphology and locomotor performance; thermal thresholds unknown	Rushikulya and Chennai, India (Pusapati et al. 2021)

success and hatchling survival (Dial 1987; Rusli et al. 2016).

Another practice of concern is the use of intermittent shading and watering (Wood et al. 2014; Hill et al. 2015; Jourdan and Fuentes 2015) to reduce high nest temperatures without monitoring nest temperatures. High nest temperatures may be lethal to sea turtle embryos or result in feminization of populations as sea turtles have temperature-dependent sex determination, so nest temperatures that differ greatly from the nesting beach could alter the sex ratio of hatchlings entering the population (Mrosovsky and Yntema 1980; Morreale et al. 1982; Pintus et al. 2009; Sieg et al. 2011). Cooling nests unnecessarily, however, could have unforeseen impacts (Santridián Tomillo et al. 2021) so the need for temperature mitigation and success of the intervention should be assessed. As a new best practice, we recommend that hatcheries monitor their nest temperatures to determine when shading and/or watering might be required throughout the nesting season. Hatchery managers should consider parameters such as those outlined in Table 4 when implementing measures to mitigate nest temperatures that exceed the upper lethal limit or transitional range of temperatures during the thermosensitive period, etc. (for potential applications see Porter et al. 2021). We suggest that shade and/or water be applied to mimic temperature regimes on source beaches for eggs incubated in the hatchery.

Hatchling fitness was not directly assessed but can be inferred from practices in holding, housing, and releasing hatchlings. Ideally, hatchlings would be released from hatcheries soon after emergence from the nest. If hatcheries can only be checked for emerged hatchlings at long intervals throughout the night, caging nests would minimize hatchling movements after emergence and, therefore, maintain energy reserves required for hatchling activities after release. Swimming of hatchlings in buckets or tanks of water will likely deplete their energy reserves which, in turn, will affect their swimming speed and style during the frenzied swim through coastal waters to avoid predators (Pilcher and Enderby 2001). Holding hatchlings in conditions such as those described in some responses to this survey and in published literature (such as Sundaram et al. 2019) would result in decreased hatchling fitness and survivorship.

Social desirability bias in estimates of hatching success reported to us was anticipated, and detected, so we did not use hatchling production in statistical comparisons with nests incubated *in situ* or in hatcheries in other countries. Assessment using data reported in the literature indicated that the hatching success of eggs incubated in hatcheries in India does not differ significantly to that of *in situ* nests or clutches relocated to other hatcheries in the region, although it is lower than the former and higher than the latter. Hatcheries create protected environments with optimal conditions for hatching success and incubation of eggs and should result in a higher hatching success than *in situ* nests potentially threatened by biological and anthropogenic factors. Production of hatchlings from nests relocated to hatcheries will be optimized by following best practices.

Recommendations.—The main hatchery practices in need of improvement are relocation interval and the holding of hatchlings, especially in water, after emergence, as these have negative implications for hatchling production and fitness respectively. Egg transport containers, nest density, and nest depth should also meet best practices. In addition, initiatives that mitigate the potential impact of high nest temperatures should include monitoring to ensure it is required and effective, such as the approach at a hatchery in Myanmar described by Howard et al. (2019). Some hatcheries in India have been proactive in refining their practices in response to environmental conditions and/or hatchling production. For example, Shanker (1994) described shading of Olive Ridley Turtle nests to mitigate high temperatures and increasing the distance between nests to improve hatching success. Dharini (2007) also shaded their hatcheries after observing lower hatching success in Olive Ridley Turtle clutches when temperatures increased in late summer. Andrews et al. (2001) reported an increase in hatching success of Leatherback Turtle eggs after hatchery practices were modified (specific details not provided) in response to concern that relocated nests were not resulting in greater hatchling production than *in situ* nests. Gani (2000) described a change in method of locating *in situ* Olive Ridley Turtle nests when using a stick to probe for soft areas of sand resulted in damage to eggs. These examples suggest that many hatchery personnel would be open to reviewing and changing their practices to achieve conservation goals.

Both human and financial resources may limit changes to practices of established hatcheries. Human capital can be increased through the provision of regular opportunities for capacity building facilitated by experienced researchers and written guides (in appropriate languages) for hatchery operations. Motivation to refine hatchery practices might be low without the understanding that the current hatchling production does not exceed that of nests left vulnerable to threats on the nesting beach. Pullin and Knight (2003) proposed a paradigm shift in stakeholder engagement with conservation practices, which could be scaled for hatcheries in India, although there may be a difference in the potential involvement of personnel at state Forest

Department hatcheries and those managed by NGOs or volunteer groups. An analytical cross-sectional study to identify factors that would most effectively enhance hatchery resources and personnel capital would be most appropriate as the conditions of state permits issued to NGOs/volunteer groups and terms of employment for Forest Department staff may limit their potential to change current practices.

A quantitative assessment of hatchery practices and records is also likely to be of benefit. But without accurate records of the number of clutches and eggs incubated in the hatchery, and calculations of hatching and emergence success for each nest and as an annual assessment for the hatchery, it will be challenging for hatchery managers or external researchers to reflect on practices that may require improvement and the overall contribution to sea turtle conservation. The annual number of eggs incubated and/or hatchlings released are commonly reported but these are not rigorous metrics, and the reporting of these numbers alone by hatcheries in India has long been criticized (Frazier 1989).

We also renew the call begun by Frazier (1989) and Shanker (1994) for more hatcheries to consider the *in situ* protection of clutches where possible (occurring recently at locations in Goa and Gujarat; this study), especially on beaches with low nesting density where monitoring cannot occur frequently enough that eggs are moved to hatcheries within the 6 h. Nests on such beaches can be protected *in situ* without disturbance to developing embryos at any time after oviposition, although previous attempts have not been successful, with several examples summarized by Shanker (2015). Excluding predators requires the construction of a natural (e.g., comprising branches or sticks) or artificial (e.g., constructed of wire mesh) barricade around the nest and the design would depend on the size, strength, and digging ability of common predators on individual beaches (Phillott 2020). Nests protected in this way require frequent monitoring on dates estimated to be close to emergence so that hatchlings can be released as close to the time of surfacing as possible, but *in situ* protection that allows hatchlings to freely navigate their way to the ocean would reduce the potential adverse effects of long relocation intervals and holding hatchlings.

Acknowledgments.—We thank FLAME University and the Marine Section Conservation Small Grants Program of the Society for Conservation Biology for funding to conduct field interviews. The providers of funding for the study played no role in study design, collection, analysis, and interpretation of data, writing of the report, or the decision to submit the article for publication. Discussions with Kartik Shanker and Muralidharan Manoharakrishnan about sea turtle hatcheries in India and their practices were greatly valued, as were the survey responses and hospitality offered by all who contributed to the study.

Literature Cited

Abd Mutalib, A.H.A., and N. Fadzly. 2015. Assessing hatchery management as a conservation tool for sea turtles: a case study in Setiu, Terengganu. Ocean & Coastal Management 113:47e53. https://doi.org/10.1016/j.ocecoaman.2015.05.010.

Ackerman, R.A. 1997. The nest environment and embryonic development of sea turtle. Pp. 83–106 *In* The Biology of Sea Turtles. Lutz, P.L., and J.A. Musick (Eds.) CRC Press, Boca Raton, Florida, USA.

Almeida, A.d.P., and S.L. Mendes. 2007. An analysis of the role of local fishermen in the conservation of the Loggerhead Turtle (*Caretta caretta*) in Pontal do Ipiranga, Linhares, ES, Brazil. Biological Conservation 134:106–112.

Andrews, H.V., S. Krishnan, and P. Biswas. 2001. The distribution and status of marine turtles around the Andaman and Nicobar Archipelago. Sea Turtle Project Report, IND/97/964, Government of India/United Nations Development Programme, Chennai, India. 30 p.

Arun, V. 2019. Turtle diary, 2018 - Students Sea Turtle Conservation Network. Thirty years of sea turtle conservation on the Chennai coast. Indian Ocean Turtle Newsletter 30:2–5.

Behera, S., B. Tripathy, K. Sivakumar, and B.C. Choudhury. 2013. A case study of Olive Ridley (*Lepidochelys olivacea*) solitary nests in Gahirmatha rookery, Odisha, India. Testudo 7:49–60.

Blanck, C.E., and R.H. Sawyer. 1981. Hatchery practices in relation to early embryology of the Loggerhead Sea Turtle *Caretta caretta* (Linné). Journal of Experimental Marine Biology and Ecology 49:163–177.

Dharini, S. 2007. Importance of temperature in *ex situ* hatchery management in Chennai. Indian Ocean Turtle Newsletter 6:14–15.

Dial, B.E. 1987. Energetics and performance during nest emergence and the hatchling frenzy in Loggerhead Sea Turtles (*Caretta caretta*). Herpetologica 43:307–315.

Dutton, D.L., P.H. Dutton, M. Chaloupka, and R.H. Boulon. 2005. Increase of a Caribbean Leatherback Turtle *Dermochelys coriacea* nesting population linked to long-term nest protection. Biological Conservation 126:186–194.

Eckert, K.L., and S.A. Eckert. 1990. Embryo mortality and hatch success in *in situ* and translocated Leatherback Sea Turtle *Dermochelys coriacea* eggs. Biological Conservation 53:37–46.

Frazier, J. 1989. Survey of the marine turtle hatcheries of Karnataka. Hamadryad 14:8–18.

Gani, M.O. 2000. The Olive Ridley Turtles (*Lepidochelys olivacea*) of Sundarbans coast. Tigerpaper 27:7–11.

Harry, J.L., and C.J. Limpus. 1989. Low-temperature protection of marine turtle eggs during long-distance relocation. Australian Wildlife Research 16:317–320.

Hill, J.E., F.V. Paladino, J.R. Spotila, and P. Santridián Tomillo. 2015. Shading and watering as a tool to mitigate the impacts of climate change in sea turtle nests. PLoS ONE 10: e0129528. https://doi.org/10.1371/journal.pone.0129528.

Honarvar, S., M.P. O'Connor, and J.R. Spotila. 2008. Density-dependent effects on hatching success of the Olive Ridley Turtle, *Lepidochelys olivacea*. Oecologia 157:221–230.

Howard, R., K. Myint, P. Maw, P.Z. Oo, and M. Tiwari. 2019. Improving marine turtle conservation in Myanmar. Oryx 53:409.

Hunt, J., and D. Hodgson. 2010. What is fitness, and how do we measure it? Pp. 46–70 *In* Evolutionary Behavioral Ecology. Westneat, D.F., and C.W. Fox (Eds.). Oxford University Press Inc, New York, New York, USA.

Jourdan, J., and M.M.P.B. Fuentes. 2015. Effectiveness of strategies at reducing sand temperature to mitigate potential impacts from changes in environmental temperature on sea turtle reproductive output. Mitigation and Adaptation Strategies for Global Change 20:121–133.

Kale, N., M. Manoharakrishnan, and K. Shanker. 2016. The olive currency: a comparative account of community based ecotourism ventures in Western India. Indian Ocean Turtle Newsletter 23:2–6.

Limpus, C.J., V. Baker, and J.D. Miller. 1979. Movement induced mortality of Loggerhead eggs. Herpetologica 35:335–338.

Manoharakrishnan, M., and A. Swaminathan. 2020. India. Pp. 78–108 *In* Sea Turtles in the Middle East and South Asia Region: MTSG Annual Regional Report 2020. Phillott, A.D., and A.F. Rees. (Eds.). Report of the International Union for Conservation of Nature/Species Survival Commission Marine Turtle Specialist Group, Gland, Switzerland.

Margoluis, R., C. Stem, N. Salafsky, and M. Brown. 2009. Design alternatives for evaluating the impact of conservation projects. Pp. 85–96 *In* Environmental Program and Policy Evaluation: Addressing Methodological Challenges. Birnbaum, M., and P. Mickwitz (Eds.). New Directions for Evaluation 122. https://doi.org/10.1002/ev.298.

Maulany, R.I., D.T. Booth, and G.S. Baxter. 2012a. Emergence success and sex ratio of natural and relocated nests of Olive Ridley Turtles from Alas Purwo National Park, East Java, Indonesia. Copeia 2012:738–747.

Maulany, R.I., D.T. Booth, and G.S. Baxter. 2012b. The effect of incubation temperature on hatchling quality in the Olive Ridley Turtle, *Lepidochelys olivacea*, from Alas Purwo National Park, East Java, Indonesia: implications for hatchery management. Marine Biology 159:2651–2661.

Mazaris, A.D., S. Kramer-Schadt, J. Tzanopoulos, K. Johst, G. Matsinos, and J.D. Pantis. 2009. Assessing the relative importance of conservation measures applied on sea turtles: comparison of measures focusing on nesting success and hatching recruitment success. Amphibia-Reptilia 30:221–231.

Mazaris, A.D., G. Schofield, C. Gzakinou, V. Almpanidou, and G.C. Hays. 2017. Global sea turtle conservation successes. Science Advances 3:e1600730. https://doi.org/10.1126/sciadv.1600730.

Merchant-Larios, H., S. Ruiz-Ramirez, N. Moreno-Mendoza, and A. Marmolejo-Valencia. 1997. Correlation among thermosensitive period, estradiol response, and gonad differentiation in the sea turtle, *Lepidochelys olivacea.* General and Comparative Endocrinology 107:373–385.

Miller, J.D. 1999. Determining clutch size and hatching success. Pp. 124–129 *In* Research and Management Techniques for the Conservation of Sea Turtles. Eckert, K.L., K.A. Bjorndal, F.A. Abreu-Grobois, and M. Donnelly (Eds.). International Union for Conservation of Nature/Species Survival Commission Marine Turtle Specialist Group Publication No. 4.

Mohanty-Hejmadi, P., and M.T. Dimond. 1986. Temperature dependent sex determination in the Olive Ridley Turtle. Progress in Clinical and Biological Research 217A:159–162.

Mohanty-Hejmadi, P., M. Behera, and M.T. Dimond. 1985. Temperature dependent sex differentiation in the Olive Ridley *Lepidochelys olivacea* and its implications for conservation. Pp 260–263. *In* Proceedings of the Symposium on Endangered Marine Animals and Marine Parks. Silas, E.G. (ed.). The Marine Biological Association of India, Cochin, India.

Morreale, S.J., G.J. Ruiz, J.R. Spotila, and E.A. Standora. 1982. Temperature-dependent sex determination: current practices threaten conservation of sea turtles. Science 216:1245–1247.

Mortimer, J.A. 1999. Reducing threats to eggs and hatchlings: hatcheries. Pp. 174–178 *In* Research and Management Techniques for the Conservation of Sea Turtles. Eckert, K.L., K.A. Bjorndal, F.A. Abreu-Grobois, and M. Donnelly (Eds.). International Union for Conservation of Nature/ Species Survival Commission Marine Turtle Specialist Group Publication No. 4.

Mrosovsky N. 1983. Conserving Sea Turtles. British Herpetological Society, London, UK.

Mrosovsky, N., and C.L. Yntema. 1980. Temperature dependence of sexual differentiation in sea turtles: implications for conservation practices. Biological Conservation 18:271–280.

Mrosovsky, N., and C. Pieau. 1991. Transitional range of temperature, pivotal temperatures and thermosensitive stages for sex determination in reptiles. Amphibia-Reptilia 12:169–179.

Newing, H., C.M. Eagle, R.K. Puri, and C.W. Watson. 2011. Conducting Research in Conservation: Social Science Methods and Practice. Routledge, London, UK.

Parmenter, C.J. 1980. Incubation of the eggs of the Green Sea Turtle, *Chelonia mydas*, in Torres Strait, Australia: the effect of movement on hatchability. Australian Wildlife Research 7:487–491.

Phillott, A.D. 2020. Protection of *in situ* sea turtle nests from depredation. Indian Ocean Turtle Newsletter 32:31–40.

Phillott, A.D., and N. Kale. 2018. The use of sea turtle hatcheries as an *ex situ* conservation strategy in India. Indian Ocean Turtle Newsletter 27:18–29.

Phillott, A.D., and K. Shanker. 2018. Best practices in sea turtle hatchery management for South Asia. Indian Ocean Turtle Newsletter 27:31–34.

Pilcher, N.J., and S. Enderby. 2001. Effects of prolonged retention in hatcheries on Green Turtle (*Chelonia mydas*) hatchling swimming speed and survival. Journal of Herpetology 35:633–638.

Pintus, K.J., B.J. Godley, A. McGowan, and A.C. Broderick. 2009. Impact of clutch relocation on Green Turtle offspring. Journal of Wildlife Management 73:1151–1157.

Porter, E., D.T. Booth, C.J. Limpus, M.N. Staines, and C.E. Smith. 2021. Influence of short-term temperature drops on sex-determination in sea turtles. Journal of Experimental Zoology-A Ecological and Integrative Physiology 335:649–648.

Pritchard, P.C.H. 1980. The conservation of sea turtles: practices and problems. American Zoology 20:609–617.

Pullin, A.S., and T.M. Knight. 2001. Effectiveness in conservation practice: pointers from medicine and public health. Conservation Biology 15:50–54.

Pullin, A.S., and T.M. Knight. 2003. Support for decision making in conservation practices: an evidence-based approach. Journal of Nature Conservation 11:83–90.

Pusapati C., M. Manoharakrishnan, A.D. Phillott, and K. Shanker. 2021. Effect of hatchery nest environment on Olive Ridley *(Lepidochelys olivacea)* hatchling performance. Chelonian Conservation and Biology 20:60–70.

Rashid, S.M.A., and M.Z. Islam. 2006. Status and conservation of marine turtles in Bangladesh. Pp. 200–216 *In* Marine Turtles of the Indian Subcontinent. Shanker, K., and B. Choudhury (Eds.). Universities Press, Hyderabad, Telangana, India.

Revuelta, O., Y.M. León, A.C. Broderick, P. Feliz, B.J. Godley, J.A. Balbuena, A. Mason, K. Poulton, S. Savoré, J.A. Raga, and J. Tomás. 2015. Assessing the efficacy of direct conservation interventions: clutch protection of the Leatherback Marine Turtle in the Dominican Republic. Oryx 49:677–686.

Rusli, M.U., and D.T. Booth. 2016. Bigger clutch sizes save offspring energy during nest escapes. Behavioural Ecology and Sociobiology 70:607–616.

Rusli, M.U., D.T. Booth, and J. Joseph. 2016. Synchronous activity lowers the energetic cost of nest escape for sea turtle hatchlings. Journal of Experimental Biology 219:1505–1513.

Rusli, M.U., J. Joseph, H-C. Liew, and Z. Bachok. 2015. Effects of egg incubation methods on locomotor performances of Green Turtle (*Chelonia mydas*) hatchlings. Sains Malaysia 44:49–55.

Santridián Tomillo, P., B.P. Wallace, F.V. Paladino, J.R. Spotila, and M. Genovart. 2021. Short-term gain, long-term loss: how a widely-used conservation tool could further threaten sea turtles. Biological Conservation 261:109260. https://doi.org/10.1016/j.biocon.2021.109260.

Sari, F., and Y. Kaska. 2017. Assessment of hatchery management for the Loggerhead Turtle (*Caretta caretta*) nests on Göksu Delta, Turkey. Ocean & Coastal Management 146:89–98.

Schäuble, C., K. Ibrahim, A.R. Kassim, M. Hamann, and J. Whittier. 2002. Monitoring hatchery success - What's worthwhile? Pp. 308 *In* Proceedings of the 22nd Annual Symposium on Sea Turtle Biology and Conservation. Seminoff, J.A. (Comp.). Technical Memorandum NMFS-SEFSC-503, National Oceanic and Atmospheric Administration, Miami, Florida USA.

Shanker, K. 1994. Conservation of sea turtles on the Madras coast. Marine Turtle Newsletter 64:3–6.

Shanker, K. 2015. From Soup to Superstar: The Story of Sea Turtle Conservation Along the Indian Coast. HarperLitmus, Noida, Uttar Pradesh, India.

Shenoy, S., R. Berlie, and K. Shanker (Comps.). 2011. A Comprehensive Field Guide to Research, Monitoring and Conservation. Dakshin Foundation, Bangalore, Karnataka, India and Madras Crocodile Bank Trust, Mamallapuram, Tamil Nadu, India.

Sieg, A.E., C.A. Binckley, B.P. Wallace, P. Santidrián Tomillo, R.D. Reina, F.V. Paladino, and J.R. Spotila. 2011. Sex ratios of Leatherback Turtles: hatchery translocation decreases metabolic heating and female bias. Endangered Species Research 15:195–204.

Spanier, M.J. 2010. Beach erosion and nest site selection by the Leatherback Turtle *Dermochelys coriacea* (Testudines: Dermochelyidae) and implications for management practices at Playa Gandoca, Costa Rica. Revista de Biologia Tropical 58:1237–1246.

Sundaram, S., N.J. James, and T.M. Abdul Saleem. 2020. Impact of NGO driven conservation activities on local sea turtle populations at Chavakkad Beach, Kerala, India. Indian Ocean Turtle Newsletter 31:18–20.

Sundaram, S., N.J. James, and A. Saleem. 2019. Conservation activities carried out on Olive Ridley Turtles, *Lepidochelys olivacea* (Eschscholtz, 1829) and observations on its hatching from Chavakkad Beach, Kerala, India. International Journal of Life Science 7:83–91.

Sutherland, W.J., W.M. Adams, R.B. Aronson, R. Aveling, T.M. Blackburn, S. Broad, G. Ceballos, I.M. Côté, R.M. Cowling, G.A.B. da Fonseca, E. Dinerstein, et al. 2009. One hundred questions of importance to the conservation of global biological diversity. Conservation Biology 23:557–567.

Sutherland, W.J., A.S. Pullin, P.M. Dolman, and T.M. Knight. 2004. The need for evidence-based conservation. Trends in Ecology and Evolution 19:305–308.

Tripathy, B., and P.S. Rajasekhar. 2009. Natural and anthropogenic threats to Olive Ridley Sea Turtles (*Lepidochelys olivacea*) at the Rushikulya rookery of Orissa coast, India. Indian Journal of Marine Science 38:439–443.

Turtle Action Group (TAG). 2011. The Turtle Action Group: a network of NGOs dedicated to the conservation of sea turtles and their habitats in India. Indian Ocean Turtle Newsletter 13:1–2.

Valverde, R.A., S. Wingard, F. Gómez, M.T. Tordoir, and C.M. Orrego. 2010. Field lethal incubation temperature of Olive Ridley Sea Turtle *Lepidochelys olivacea* embryos at a mass nesting rookery. Endangered Species Research 12:77–86.

van de Merwe, J., K. Ibrahim, and J. Whittier. 2005. Effects of hatchery shading and nest depth on the development and quality of *Chelonia mydas* hatchlings: implications for hatchery management in Peninsular, Malaysia. Australian Journal of Zoology 53:205–211.

van de Merwe, J., K. Ibrahim, and J.M. Whittier. 2013. Post-emergence handling of Green Turtle hatchlings: improving hatchery management worldwide. Animal Conservation 16:316–323.

Wallace B.P., A.D. DiMatteo, B.J. Hurley, E.M. Finkbeiner, A.B. Bolten, M.Y. Chaloupka, B.J. Hutchinson, F.A. Abreu-Grobois, D. Amorocho, K.A. Bjorndal, et al. 2010. Regional management units for marine turtles: a novel framework for prioritizing conservation and research across multiple scales. PLoS ONE. 5:e15465. https://doi.org/10.1371/journal.pone.0015465.

Williamson, S.A., R.G. Evans, and R.D., Reina. 2017. When is embryonic arrest broken in turtle eggs? Physiological and Biochemical Zoology 90:523–532.

Wood, A., D.T. Booth, and C.J. Limpus. 2014. Sun exposure, nest temperature and Loggerhead Sea Turtle hatchlings: implications for beach shading management strategies at sea turtle rookeries. Journal of Experimental Marine Biology and Ecology 451:105–114.

Wyneken, J. 2000. The migratory behaviour of hatchling sea turtles beyond the beach. Pp. 121–142 *In* Sea Turtles of the Indo-Pacific. Pilcher, N.J., and G. Ismail (Eds.). ASEAN Academic Press, London, UK.

Wyneken, C.L., T.J. Burke, M. Salmon, and D.K. Pederson. 1998. Egg failure in natural and relocated sea turtle nests. Journal of Herpetology 22:88–96.

Yntema, C.L., and N. Mrosovsky. 1982. Critical periods and pivotal temperatures for sexual differentiation in Loggerhead Sea Turtles. Canadian Journal of Zoology 60:1012–1016.

Andrea D. Phillott became engaged with sea turtle research and monitoring as an undergraduate student and subsequently studied fungal invasion of sea turtle nests in eastern Australia for her Ph.D. After earning her doctorate, she worked at Central Queensland University and James Cook University in Australia, teaching and conducting research on the biology and disease ecology of turtles and frogs. Andrea subsequently moved to the Asian University for Women in Chittagong, Bangladesh, and is now a Professor at FLAME University in Pune, India. She continues research on sea turtle biology and conservation, with a special focus on populations in South and Southeast Asia. (Photographed by Elissa Rice).

Nupur Kale became interested in sea turtle research and conservation while conducting her Master's thesis on Green Turtle conservation techniques and their efficacy in Sri Lanka. Ever since, she has been part of sea turtle monitoring projects in Odisha, Maharashtra, and the Lakshadweep Archipelago (India) and Tortuguero (Costa Rica). Currently she is working as a Project Associate for the Marine Conservation Program at Wildlife Conservation Society-India. (Photographed by Manini Bansal).

Abhidnya Unhale became interested in marine biology while studying for her Master's thesis on marine algae in Kelshi, Maharashtra. Her passion for sea turtle biology became profound when she volunteered with Sahyadri Nisarg Mitra for the annual turtle festival at Anjarle. This experience was followed by a research project initiated by Gujarat Institute of Desert Ecology on coastal sand dune along Ratnagiri coast of India. She is now engaged as Project Personnel with Bioconcepts, Pune, India. (Photographed by Mohan Upadhye).

Appendices

Questionnaire/Interview Questions

1. What is the name of your hatchery and the managing NGO or organization (if applicable)?
2. Where is the hatchery located? Please name the village or town, district, state and country.
3. How many years has the hatchery been operating?
4. Please describe your role in the hatchery/NGO/organisation (if applicable):
5. What is the main purpose of the hatchery? e.g., conservation, ecotourism, turtle farming, protection from predators, protection from illegal take.
6. How many people does this hatchery employ?
7. Please describe the egg incubation enclosures in your hatchery:
   a. What material is the fence is made from? How high is your fence? Is there a locked gate or guard?
   b. Does your hatchery have a roof or shade? If yes, what material is it made from?
   c. Is your hatchery in a permanent position or is it moved every year or every few years?
   d. If your hatchery is in a permanent position, for how long has it been there?
   e. If your hatchery is in a permanent position, is the sand ever cleaned? How often? How is it cleaned?
   f. If your hatchery is moved between nesting seasons, how often is it moved?
8. How many beaches are the eggs in your hatchery collected from? Please provide the name of the beach, species of turtle, and number of nests or eggs in the table below. Use one line for each beach from which you collect eggs.

Further comments:

9. Please describe the methods of egg collection and transport to the hatchery in the table below. Use one line for each beach from which you collect eggs.

Further comments:

10. Do you buy eggs from egg collectors? What species of eggs are provided by egg collectors and from how many egg collectors? What is the cost per egg? Do you purchase all available eggs?
11. Please describe the arrangement of nests in your hatchery. Use one line in the table below for each species and describe the nest density (nests per sq. m), distance between nests (cm or m), depth of nest (cm), mounding of sand on top of the nest (Y/N), and marking of nests (Y/N).

Further comments:

12. Please describe the productivity of nests in your hatchery. Use one line in the table below for each species and record the average hatching success (%), monitoring of nest temperature with data loggers or thermometers (Y/N), regulation of nest temperature (Y/N), watering of nests (Y/N; If Y then how often?

Further comments:

13. Please describe the holding and release of hatchlings after they have emerged from the nest.
    a. How long between hatchling emergence from the nest and release to the ocean.
    b. Do you hold hatchlings between emergence from the nest and release to the ocean? If yes, please answer the questions below.
       i. Do you hold the hatchlings in a dry bucket/tank or a bucket/tank with water before release to the ocean?
       ii. At what time are hatchlings released each day?
       iii. Do tourists or local people watch the hatchlings being released?
14. Does your hatchery need a government permit to operate? If yes, what is the name of the permit?
15. Has the hatchery manager and/or staff participated in a hatchery management workshop?
16. Does your hatchery maintain records of the number of eggs or nests collected annually, hatch success, number of hatchlings released etc.? Do you have to report this information to anyone?
17. Does your hatchery follow any hatchery guidelines for its operation? Who published the guidelines?
18. Have you ever published a report or scientific paper about your hatchery? If yes, where was it published?

Appendix Table 1. Hatching success of sea turtle clutches incubated *in situ* and in hatcheries in India and elsewhere in the northern Indian Ocean. The percentage (%) hatchling success is the mean %. SD = standard deviation.

Sea Turtle	Location	Nesting Season	# Clutches (C) or # Eggs (E)	% Hatching Success ± SD (Range)	Source
In situ in India					
Olive Ridley	Rushikulya, India	2008–2015	C 5, 362	83 (66–93)	Chandarana et al. 2017
	Vishakapatnam, Gangavaram and Pudimaka coast, India	1999	C 389	70 (-)	Nath 2000
In situ elsewhere in northern Indian Ocean					
Green	Zabargad Island, Egypt	2001–2008	C 8	87 ± 7 (71–96)	Hanafy 2012
	Qaruh and Umm Al-Maradim, Is., Kuwait	2004–2005	C 73	75 (-)	Al-Mohanna et al. 2014
	Jana, Karan and Kurain Islands, Saudi Arabia	1991–1992	C 21	85 (54–97)	Pilcher 2000
	Ras Baridi Coast, Saudi Arabia	1989–1992	C 28	80 ± 16 (32–99)	Pilcher and Al-Merghani 2000
	Kosgoda, Sri Lanka	2003–2008	C 526	77 ± 22 (66–81)	Ekanayake et al. 2016
Hawksbill	Big Giftun Island, Egypt	2001–2008	C 11	67 ± 13 (53–96)	Hanafy 2012
	Qaru and Umm Al Maradim, Kuwait	2010–2013	C 16	58 ± 26 (6–96)	Rees et al. 2020
	Nakhiloo Island, Iran	2011	C 19	44 (-)	Pazira et al. 2016
	Kish Island, Iran	2009–2012	-	76 (-)	Hesni et al. 2016
	Shidvar Island, Iran	2012	C 35	79 (-)	Zare et al. 2012
	Fuwairit Beach, Qatar	2005	C 22	73 ± 20 (14–97)	Pilcher 2006
	Ras Laffan Industrial City, Qatar	2001–2002	C 17	86 ± 15 (44–100)	Tayab and Quiton 2003
Hatcheries in India					
Olive Ridley	Agonda, Goa	2000/01	C 0–9	85 (-)	Giri and Chaturvedi 2006
	Galgibaga, Goa	1999/00–2000/01	C 43	78 (-)	Giri and Chaturvedi 2006
	Morjim, Goa	1997/98–2000/01	C 57	64 (-)	Giri and Chaturvedi 2006
	Ramayapatana, Odisha	2012/13	C 195	95 ± 2 (87–100)	Behera and Kar 2013
	Rushikulya, Odisha	2009/10–2015/16	C about 30	63 (49–79)	Chandarana et al. 2017
	Unnamed location in Udupi district, Karnataka	2004/05–2005/06	E 2,348	76 (-)	McCann 2007
	Panaiyur Kuppam, Tamil Nadu	2005/06–2006/07	C 10	21 (-)	Dharini 2007
	Nainar Kuppam, Tamil Nadu	2005/06–2006/07	C 20	62 (-)	Dharini 2007
	Point Calimere, Tamil Nadu	2000	C 14	76 (-)	Baruah 2001
	Koolaiyar, Madavamedu, Point Calimere, Tharangambadi and Vanagiri, Tamil Nadu	2005/06–2008/09	E 14, 366	49 (-)	Velusamy and Sundararaju 2009
Hatcheries elsewhere in the northern Indian Ocean					
Olive Ridley	Sonadia Island, Bangladesh	2009/10	C 43	92 ± 5 (-)	Islam et al. 2011
	Sandspit and Hawkesbay beaches, Pakistan	1980–1997	C 654	27 (6–74)	Firdous 2001; Firdous et al. 2011
	P a Thong Island, Thailand	1998/99–2002/03	C 18	84 (71–97)	Aureggi and Chantrapornsyl 2006
Green	Oyster, Thameehla, Moscos and Kandongalay Islands, Myanmar	2017/18	C 81	70 ± 19 (-)	Howard et al. 2019
	Sandspit and Hawkesbay beaches, Pakistan	1979–1997	C 17, 048	26 (11–43)	Firdous 2001; Firdous et al. 2011
Hawksbill	Nakhiloo Island, Iran	2011	C 19	55 (-)	Pazira et al. 2016

Table Literature Cited

Al-Mohanna, S.Y., A.S.Y. Al-Zaidan, and P. George. 2014. Green Turtles (*Chelonia mydas*) of the north-western Arabian Gulf, Kuwait: the need for conservation. Aquatic Conservation 24:166–178.

Aureggi, M., and S. Chantrapornsyl. 2006. Reproductive biology and conservation of the Olive Ridley Turtle at Phra Thong Island, Andaman Sea, Thailand. Research Bulletin (Sun Chiwawitthaya thang Thale Phuket) 67:81–87.

Baruah, A.D. 2001. Olive Ridley hatchery program of Point Calimere Wildlife Sanctuary, Tamil Nadu. Kachhapa 5:20.

Behera, S.K., and C. Kar. 2013. Solitary nesting and mortality of Olive Ridley Sea Turtles along the Ganjam Coast of Odisha, India. Indian Ocean Turtle Newsletter 18:8–11.

Chandarana, R., M. Manoharakrishnan, and K. Shanker. 2017. Long-term monitoring and community-based conservation of Olive Ridley Turtles in Odisha. CMPA Technical Series No. 7. Indo-German Biodiversity Programme, GIZ-India, New Delhi. http://www.indo-germanbiodiversity.com/publications.html [Accessed 11 January 2021].

Dharini, S. 2007. Importance of temperature in *ex situ* hatchery management in Chennai. Indian Ocean Turtle Newsletter 6:14–15.

Ekanayake, E.M.L., T. Kapurusinghe, M.M. Saman, D.S. Rathnakumara, P. Samaraweera, and R.S. Rajakaruna. 2016. Reproductive output and morphometrics of Green Turtle, *Chelonia mydas*, nesting at the Kosgoda rookery in Sri Lanka. Ceylon Journal of Science 45:103–116.

Firdous, F. 2001. Sea turtle conservation and education in Karachi, Pakistan. Asean Review of Biodiversity and Environmental Conservation (ARBEC). http://www.arbec.com.my/pdf/art5julysept01.pdf [Accessed 11 January 2021].

Firdous, F., S. Barkati, and S. Rahman. 2011. Studies on transplantation of marine turtle nests at Karachi coast (Sindh), Pakistan. Pakistan Journal of Scientific and Industrial Research Series B: Biological Science 54:29–33.

Giri, V., and N. Chaturvedi. 2006. Sea turtles of Maharashtra and Goa. Pp. 147–155 *In* Marine Turtles of the Indian Subcontinent. Shanker, K., and B.C. Choudhury (Eds.), Universities Press, Hyderabad, Telangana, India.

Hanafy, H.M. 2012. Nesting of marine turtles on the Egyptian beaches of the Red Sea. Egypt Journal of Aquatic Biology and Fisheries 16:59–71.

Hesni, M.A., M. Tabib,and A.H. Ramaki. 2016. Nesting ecology and reproductive biology of the Hawksbill Turtle, *Eretmochelys imbricata*, at Kish Island, Persian Gulf. Journal of Marine Biological Association of UK 96:1373–1378.

Howard, R., K. Myint, P. Maw, P.Z. Oo, and M. Tiwari. 2019. Improving marine turtle conservation in Myanmar. Oryx 53:409.

Islam, M.Z., F. Ehsan, and M.M. Rahman. 2011. Nesting sea turtles at Sonadia Island, Bangladesh. Marine Turtle Newsletter 130:19–22.

McCann, P. 2007. Marine turtle conservation efforts in Udupi District, Karnataka. Indian Ocean Turtle Newsletter 5:10–13.

Nath, P.K. 2000. *In situ* conservation at Vishakapatnam. Kachhapa 2:16.

Pazira, A., M. Moshtaghie, M.A. Tollab, F. Ahmadi, M. Rashidi, H. Faghih, G. Ghorbanzadeh-Zaferani, D. Mirshekar, M. Shamsaie, and P. Malekpouri. 2016. Hatching success of Hawksbill Sea Turtles (*Eretmochelys imbricata*) in a protected hatchery site in Nakhiloo Island, Persian Gulf. Regional Studies in Marine Science 3:216–224.

Pilcher, N.J. 2000. The Green Turtle, *Chelonia mydas*, in the Saudi Arabian (Persian) Gulf. Chelonian Conservation Biology 3:730–734.

Pilcher, N.J. 2006. Status of Sea Turtles in Qatar. IEM Tech Report. 81 p.

Pilcher N.J., and M. Al-Merghani. 2000. Reproductive biology of Green Turtles at Ras Baridi, Saudi Arabia. Herpetological Reviews 31:142–147.

Rees, A.L., J.R. Lloyd, and N. Papathanasopoulou. 2020. Hawksbill nest and hatchling data from Kuwait. Indian Ocean Turtle Newsletter 31:13–16.

Tayab, M.R., and P. Quiton. 2003. Marine turtle conservation at Ras Laffan Industrial City, Qatar. Marine Turtle Newsletter 99:14–16.

Velusamy, T., and R. Sundararaju. 2009. Olive Ridley Turtle conservation activities along the Nagapattinam coast, Tamil Nadu, India. Indian Ocean Turtle Newsletter 10:21–24.

Zare, R., M.E. Vaghefi, and S.J. Kamel. 2012. Nest location and clutch success of the Hawksbill Sea Turtle (*Eretmochelys imbricata*) at Shidvar Island, Iran. Chelonian Conservation Biology 11:229–234.

Appendix Table 2. Characteristics of sea turtle hatcheries in India. States abbreviations are AP = Andhra Pradesh, GA = Goa, GJ = Gujarat, KA = Karnataka, KL = Kerala, MH = Maharashtra, OR = Odisha, and TN = Tamil Nadu.

	State (# hatcheries)							
	AP (n = 2)	GA (n = 3)	GJ (n = 6)	KA (n = 2)	KL (n = 2)	MH (n = 16)	OR (n = 3)	TN (n = 2)
Hatchery Purpose (%)								
Protection against predators	100	100	100	100	100	100	67	100
Protection against illegal take	100	67	0	0	100	38	0	50
Ecotourism or education	0	33	0	50	100	19	0	100
Research	0	0	0	0	0	0	33	0
Farming	0	0	0	0	0	0	0	0
Hatchery Management								
Managing body (%)								
Forest Department (FD)	0	33	100	100	0	69	67	0
NGO/Volunteer Group (VG)	100	0	0	0	100	6	33	100
Joint FD & NGO/VG	0	67	0	0	0	25	0	0
# Years operation (to 2018) (Mean ± SD (range))	- (9)	17 ± 5 (12–21)	8 ± 9 (2–25)	11 ± 1 (10–11)	14 ± 4 (11–17)	12 ± 3 (3–24)	8 ± 3 (6–11)	19 ± 13 (9–28)
# Current employees (Mean ± SD (range))	- (1)	4 ± 1 (3–4)	4 ± 1 (2–5)	2 ± 1 (1–2)	6 ± 1 (5–6)	6 ±11 (1–50)	4 ± 1 (3–4)	- (1)
Hatchery Practices								
Staff training (% Yes)	100	0	100	100	100	69	100	100
Guidelines used (% Yes)[1]	0	0	0	0	100	19	100	100
Maintain records (% Yes)	100	100	100	100	100	100	100	100
Hatchery structure (%)								
Permanent; annual sand replacement	0	0	100	0	0	0	0	0
Temporary; rebuilt annually or biannually	100	100	0	100	100	100	100	100
# Clutches/hatchery/year (Mean ± SD (range))[2]	27 ± 3 (20–35)	9 ± 10 (1–29)	29 ± 21 (8–60)	- (20)	6 ± 1 (5–7)	11 ± 9 (2–30)	173 ± 142 (10–300)	150 ± 25 (130–250)
Independent egg collectors								
% Hatcheries	0	0	0	100	50	6	0	0
# Collectors/hatchery (Mean ± SD (range))	-	-	-	7 ± 2 (4–10)	- (3)	- (20–22)	-	-
# Source beaches/hatchery (Mean ± SD (range))	6 ± 1 (5–6)	2 ± 1 (1–4)	8 ± 4 (3–14)	4 ± 1 (3–5)	2 ± 0 (2)	1 ± 0 (1–2)	1 ± 0 (1)	2 ± 1 (1–2)
Transport distance (km) (Mean ± SD (range))	6 ± 5 (3–15)	4 ± 7 (0–17)	14 ± 18 (0–78)	3 ± 4 (0–12)	2 ± 2 (0–5)	1 ± 2 (0–10)	0 ± 0 (0)	7 ± 1 (6–8)
Egg transport container (%)								
Rigid	100	100	100	50	100	69	0	0
Flexible	0	0	0	100	0	31	100	100
Mode of transport (order of frequency)	Walking motorbike	Walking motorbike	Motorbike walking	Motorbike walking	Walking bicycle, auto rickshaw	Walking motorbike	Walking	Walking
Relocation time (%)[3]								
< 3 h	0	67	0	0	50	25	33	50
3–6 h	0	33	0	100	50	25	67	50
> 6 h	100	0	100	0	0	50	0	0

Appendix Table 2 (continued). Characteristics of sea turtle hatcheries in India. States abbreviations are AP = Andhra Pradesh, GA = Goa, GJ = Gujarat, KA = Karnataka, KL = Kerala, MH = Maharashtra, OR = Odisha, and TN = Tamil Nadu.

	State (# hatcheries)							
	AP (n = 2)	GA (n = 3)	GJ (n = 6)	KA (n = 2)	KL (n = 2)	MH (n = 16)	OR (n = 3)	TN (n = 2)
Nest density (%)[4]								
< 1 per m^2	100	100	100	0	100	75	100	100
> 1 per m^2	0	0	0	100	0	25	0	0
Nest depth (cm) (Mean ± SD (range))[5]	- (46)	40 ± 18 (30-61)	102 ± 9 (76-106)	34 ± 6 (30-46)	35 ± 7 (30-40)	43 ± 6 (30-46)	- (50)	47.5 ± 0 (45-50)
Monitor nest temperatures (% Yes)	100	33	50	0	0	6	100	100
Nests shaded (% Yes)[6]	100	33	17	50	0	0	0	100
Nests watered (% Yes)[7]	100	0	17	0	0	0	0	0
Nests marked and labelled (% Yes)	100	100	100	100	100	69	100	100
Nests caged (% Yes)[8]	100	67	100	0	50	25	100	100
Holding time after hatchling emergence (%)								
< 30 min	100	67	33	0	0	63	0	0
30–60 min	0	0	0	0	0	0	67	0
Hours (range)	0	33 (3-4)	33 (2-8)	50 (7-8)	100 (unspecified)	31 (1-8)	33 (dawn, dusk)	100 (unspecified)
Days (range)	0	0	17 (1-2)	50 (2-4)	0	6 (1-2)	0	0
Months (range)	0	0	17 (1)	0	0	0	0	0
Holding conditions before hatchling release (%)								
Dry	100	67	50	50	50	64	33	50
In water	0	33	50	50	50	36	67	50
Visitors/Observers at hatchling release (% Yes)	0	33	0	50	100	50	0	100
Hatchling Production								
Annual hatching success (Mean ± SD (range))	83 ± 0 (80–85)	78 ± 3 (70–80)	85 ± 4 (80–90)	65 ± 0 (60–70)	64 ± 1 (63–65)	63 ± 10 (40–75)	85 ± 9 (75–90)	80 ± 14 (50–90)

[1]Consulted expert at local university instead.

[2]Participants from only 1 of 2 hatcheries in Karnataka responded to this question.

[3]Participants from only 1 of 6 hatcheries in Gujarat and 4 of 16 hatcheries in Maharashtra responded to this question.

[4]Participants from only 1 of 2 hatcheries in Kerala and 11 of 16 hatcheries in Maharashtra responded to this question.

[5]Participants from only 13 of 16 hatcheries in Maharashtra and 2 of 3 hatcheries in Odisha provided a numerical to this question. The remaining hatcheries dug each hatchery nest depth according to the depth of the nest from which eggs were collected.

[6]Participants from only 15 of 16 hatcheries in Maharashtra responded to this question.

[7]Participants from only 1 of 3 hatcheries in Odisha responded to this question.

[8]Participants from only 15 of 16 hatcheries in Maharashtra responded to this question.