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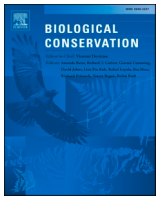

Policy analysis

Impact of 2020 COVID-19 lockdown on environmental education and leatherback sea turtle (Dermochelys coriacea) nesting monitoring in Pacuare Reserve, Costa Rica

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ABSTRACT

Sea turtles are one of the most difficult species to monitor due to their life cycle, as they spend over 90% of their lives in the ocean. Most practices used to assess species trends are implemented on nesting beaches. Pacuare Reserve has been protecting four different sea turtle species since 1989 and receives hundreds of students annually who assist with gathering data to assess each species' conservation status, primarily on the leatherback sea turtle (*Dermochelys coriacea*). However, in 2020 the COVID-19 lockdown led to the confinement of almost two-thirds of the human population, resulting in serious economic difficulties for Pacuare Reserve's operation which depends on student groups and visitors for its funding. Environmental education significantly decreased and night censuses operated from only one of two research stations to reduce costs. Census duration doubled in order to continue monitoring 5.7 km. We predict that these challenges negatively affected monitoring efforts, as measured in terms of poaching, turtle encounter rate and nest protection. Our findings reveal that the poaching rate slightly increased from 2019, possibly due to fewer censuses per night. Nest management was modified due to logistical challenges; however, a new relocation zone resulted in high hatching success despite relocating nests much farther than in previous seasons. Furthermore, researchers encountered a higher percentage of nesting turtles. Overall, the global lockdown due to COVID-19 did not weaken leatherback nesting monitoring efforts. This analysis provides lessons learned for similar efforts worldwide to ensure their robustness during times of fluctuating human and capital resources.

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1. Introduction

The 2020 COVID-19 lockdown has affected all aspects of society and has even been referred to as the Global Human Confinement Experiment. Unprecedented movement restrictions allow us to assess the impact of positive and negative consequences of large-scale confinement of the world's population and resulting reduction in human presence in biodiversity and ecosystems (Bates et al., 2020; Corlett et al., 2020).

The decline in worldwide travel has significantly decreased financial support for wildlife protection which relies heavily on tourism (Neupane, 2020). Ecotourism in particular is one of the most important economic sectors and is estimated to be responsible for 30% to 40% of tourism growth worldwide (Zacarias and Loyola, 2017). Shutdowns have disrupted funding for wildlife research projects and made wilderness areas more vulnerable to poaching and illegal fishing as the presence of law enforcement and staff has weakened (Bates et al., 2020; Fretey et al., 2020).

One vulnerable area strongly affected by the COVID-19 lockdown is Pacuare Reserve, Costa Rica. Established in 1989 to protect the tropical rainforest in the northern Caribbean coast of Costa Rica, this beach is a nesting habitat for four different sea turtles, in particular the leatherback sea turtle (*Dermochelys coriacea*). These nesting populations have been monitored since 1989 (Rivas, 2016). The other three species monitored include the green sea turtle (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*) and loggerhead (*Caretta caretta*).

Pacuare Reserve receives an average of 548 leatherback sea turtle nests per year, making it the fifth most important nesting beach for this species worldwide (IUCN, 2019; Quesada, 2020). The leatherback sea turtle is listed as "Vulnerable" by the IUCN, although many subpopulations are "Critically Endangered" (Wallace et al., 2013; IUCN,

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2019). Their numbers have historically declined due to anthropogenic threats such as climate change, fisheries bycatch, coastal habitat loss and the illegal harvest of eggs (IUCN, 2019).

Pacuare Reserve collects data on nesting females each season, protects nests through relocation and conducts environmental education with student groups. The presence of guards and night censuses conducted by research assistants and students has reduced poaching (the illegal hunting of sea turtles and their eggs) from 98% of nests to only 2% after the first year of beach protection in 1989 (Mancini et al., 2011).

Ecology Project International (EPI), an environmental education organization focused on connecting youth with nature through participation in science, has managed Pacuare Reserve since 2017 (Ecology Project International, 2019). From March through August, hundreds of foreign and local students as well as other visitors visit Pacuare Reserve, guaranteeing the project's financial sustainability by supporting the salary of the staff and living costs of the research assistants. Due to the loss of visitors, reduction in staff and financial resources during the COVID-19 lockdown, Pacuare Reserve made a number of modifications to its approach to leatherback sea turtle monitoring and nest management. For example, in 2020, Pacuare Reserve operated out of a single biological research station - the south station - instead of the north and south stations as it had in previous years.

For this study, we hypothesized that the reduction in visitors, staff, night censuses and reduced financial resources would negatively affect leatherback sea turtle conservation at Pacuare Reserve. We predicted that fewer leatherback sea turtles would be encountered, resulting in less effective nest management and consequently fewer nests protected, along with an increase in poaching.

To evaluate the effectiveness of the monitoring program during the COVID-19 lockdown, we compared the percentage of leatherback sea turtles encountered in 2020 to the previous five seasons. We also examined the poaching rate and the hatching success of relocated nests as an indicator of nest management. Determining the impact of the COVID-19 lockdown on conservation efforts will better inform future management decisions to maximize species protection at Pacuare Reserve. This analysis will provide lessons learned for similar monitoring programs to ensure their robustness during times of fluctuating human and capital resources.

2. Methods

2.1. Study site

This study was carried out along the 5.7 km (3.54 miles) beach of Pacuare Reserve, on the north Caribbean coast of Costa Rica (Fig. 1). The northern limit of the Pacuare Reserve beach is located 1 km from the mouth of the Pacuare River (north limit: 10°12′36.0″N, 83°15′57.7″W). The Mondonguillo lagoon marks the southern end of the reserve (south limit: 10°10′03.3″N, 83°14′02.4″W) which is only accessible by small boat (Rivas et al., 2016). This remote beach has a well-defined section above the high-tide line that is bordered by dense tropical vegetation dominated by coconut palms, cocoplums and sea grapes as well as some hardwood trees.

Pacuare Reserve constitutes 800 ha of tropical forest and 5.7 km of coastline (Quesada, 2019). During the nesting and hatching period, tide inundation and sand erosion are the most serious natural threats to clutches (Troëng et al., 2004; Quesada, 2017).

2.2. Leatherback sea turtle (Dermochelys coriacea) monitoring and nesting observation

Fieldwork is conducted by research assistants and field coordinators of EPl from March 1st through August 31st each year, following the predominant nesting leatherback sea turtle occurrence along the

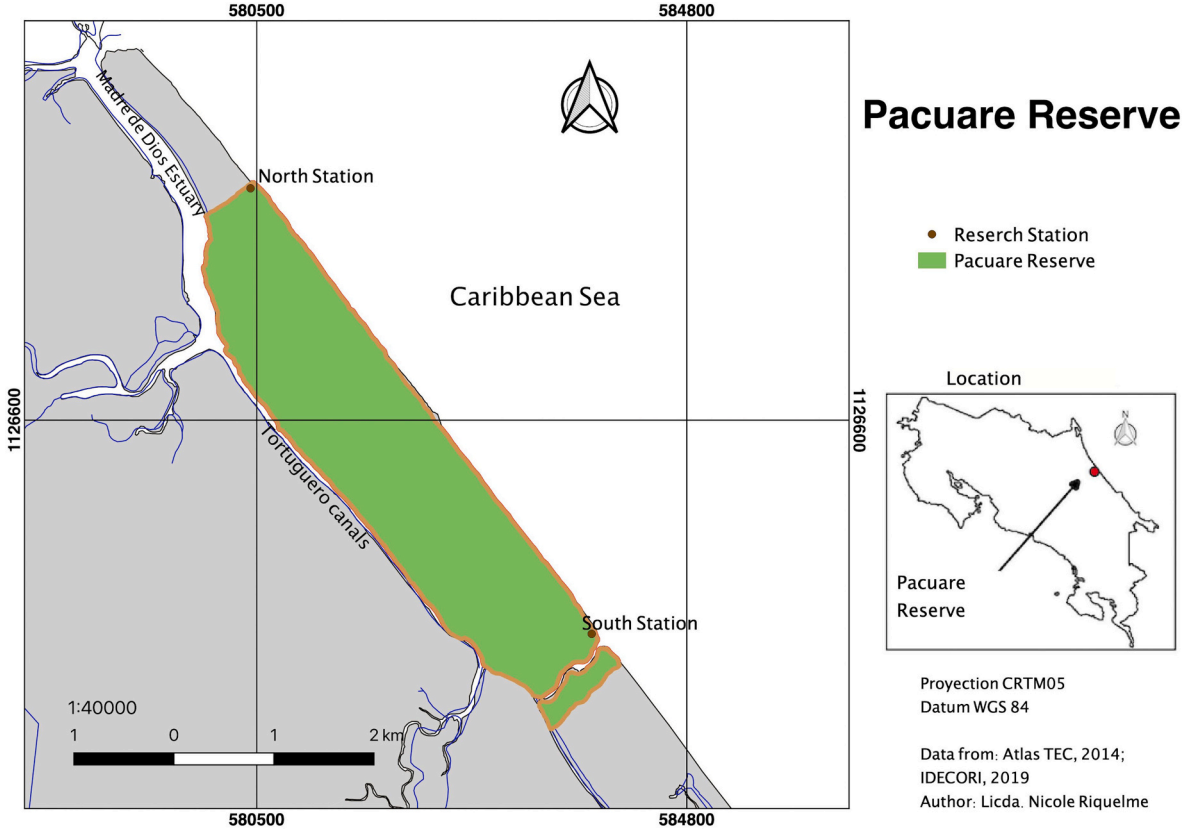

Fig. 1. Map of Pacuare Reserve, Costa Rica; from the southern to the northern limit, showing the two biological research stations and the sea turtle nesting beach monitored for this study.

Caribbean coast of Costa Rica. While night censuses have been conducted every season since the start of the monitoring program in 1989, the data used in this study analyzes leatherback sea turtle nesting from 2015 to 2020, corresponding to six nesting seasons.

For the 2015–2019 seasons, monitoring efforts operated from two biological research stations located on the southern and northern limits of Pacuare Reserve. Six research assistants worked at each station. As part of the monitoring program, the beach was divided into 100-m sections, each marked by numbered posts, which were further divided in four sections of 25 m each. Markers ranged from 0 to 57, spanning the 5.7 km in between the northern and southern limits (Bruno, 2017; Quesada, 2019).

Each night, six censuses were conducted by at least two research assistants (or one assistant if accompanied by students) beginning at 20:00, 22:00 and 00:00. Three censuses left from each station. Groups from the south station monitored the first 3 km of beach (post 0 through 30) while assistants from the north station were responsible for monitoring the northernmost half of the beach (post 30 to 57).

Ideally, both censuses met at the halfway point (post 30) to rest for 30 min before returning to their respective station. Censuses lasted from 3.5 to 4 h per shift and every leatherback sea turtle encountered was identified *via* two metal tags on her back flippers as well as a microchip in the shoulder. If no tags were found, a microchip was inserted during the egg laying process and two new tags were attached after laying eggs, with all alphanumeric codes recorded following standard protocols (Vélez, 1999; Eckert and Beggs, 2006). Events were categorized as nests, false crawls or no nest laid (if a nest attempt was observed). Two morning censuses were conducted, one from each station, to monitor both beach sections beginning at 05:00 to record any new nesting activity and mark the GPS points of original nest locations.

In 2020, a total of three night censuses were conducted from the southern station beginning at 20:00, 22:00 and 00:00. In contrast to previous years, no night censuses were performed from the north station. Monitoring censuses were conducted by two research assistants as no student groups, ecotourists or volunteers visited Pacuare Reserve after March 11st for the remainder of the season. Over the span of the 2020 nesting season, there were thirteen assistants in total. All were responsible for surveying both sections of the beach on foot (from post 0 to 57 or 5.7 km each way). One morning census was conducted daily from the south station at 05:00 to survey the entire beach.

2.3. Leatherback nest management

Egg relocation is a method often used to enhance the success of the reproductive output of threatened reptilian populations by physically moving nests to an area where they are more likely to hatch (Pike, 2008; Pfaller et al., 2009). Over the years, nest relocation has been a conservation strategy employed at Pacuare Reserve to protect nests from poachers, rising tides and beach erosion (Rivas et al., 2016).

Nests laid in areas likely to be inundated or eroded were relocated to safer sectors closer to the vegetation line with lower risk of inundation (CIT, 2011). Clutches laid in between Thursday and Sunday were also relocated to avoid illegal egg poaching which is more common on weekends. All relocated nests were transported by hand in plastic relocation bags, following relocation recommendations of CIT (2011). Laid nests were classified according to their final location (*in situ*, relocation sector or hatchery). The locations of *in situ* and relocated nests were recorded *via* triangulation methods using the beach markers near the vegetation.

During 2018 and 2019, a northern and southern hatchery were constructed, one by each respective research station. A portion of nests ranging from 19% to 33% were relocated to one of the two hatcheries based on whether the nest was laid in the northern or southern section. Both hatcheries were located in a half-shaded, well-drained area with a capacity to hold anywhere from 94 to 190 re-buried nests in sand previously sterilized at the beginning of the season with a bleach solution (Quesada, 2017). A thin black plastic mesh was placed above each hatchery to provide additional shade in order to prevent extremely high sand temperatures which stops the development process (Patino-Martinez et al., 2012).

All eggs were re-buried in holes dug to mimic the natural size and shape of leatherback sea turtle nests. For nests placed inside as well as outside the hatchery, the time of relocation along with the number of fertile and infertile eggs were recorded. All clutches inside the hatchery were protected by baskets lined in mosquito mesh to minimize fly and crab predation, and control hatching emergence (CIT, 2011).

In 2020, only one hatchery was constructed near the south station and was enclosed by plastic mesh fencing with the capacity to hold 194 nests. Once the hatchery was filled, an open sandy area bordering the hatchery and the vegetation line was prepared as a designated relocation zone. Ground vegetation was removed from the sector and a large black plastic tarp was laid out on the bordering sand to eliminate remaining plants and prevent roots from invading the nests closest to the vegetation. The black mesh identical to that used in the hatchery was utilized as a roof to create shade for the 100 (21.4% of the total number of nests) leatherback sea turtle nests placed in this zone.

When turtles were encountered during the first 5.7 km of the census, assistants were often obligated to bury clutches by the vegetation temporarily in order to continue monitoring to the north limit of Pacuare Reserve's beach. These same clutches were recovered by assistants during the return for relocation to the southern hatchery or the neighboring relocation zone. Whenever possible, assistants passed the eggs to a group who was already returning to the south station to minimize the amount of time before relocation.

During all six nesting seasons, relocated and *in situ* nests were marked *via* stakes labeled with flagging tape after 40 days of incubation (Quesada, 2019). Research assistants monitored these nests daily during the morning census for signs of hatching such as a depression, hatchling tracks or live/dead hatchlings near the nest. Each hatched nest was excavated two days after the natural emergence and hatching success was estimated for all nests. For nests where no sign of hatching was observed, excavations took place after 70 days of incubation.

2.4. Calculating hatching success

Hatching success was determined by recording the number of hatched, unhatched and pipped eggs (when the turtle has broken the shell but not fully exited the egg). Any egg shell representing more than 50% of the entire shell was counted as a hatched egg. Numerous eggshell fragments were also pieced together to estimate additional hatched eggs. Any live and dead hatchlings found in the nest were also counted. Hatching success was calculated by dividing the number of eggshells found during excavation or live hatchlings (for which the exact number was known) by the total eggs recorded during relocation. If the original number of eggs was unknown, the number of eggshells plus unhatched eggs was used (Eckert and Eckert, 1990; Rivas et al., 2016).

Hatching success was calculated for all nest locations: *in situ*, relocated, hatchery (first constructed in 2018) and the relocation zone (first constructed in 2020). We compared success rates across all conditions. We also analyzed the relationship between the distance that eggs were moved for relocation and the hatching success to determine if extended exposure to the outdoors significantly affected their survival.

3. Results

3.1. Leatherback nesting observations

During the period 2015–2020, we recorded 3290 leatherback sea turtle nests at Pacuare Reserve. The number of sea turtle nests per year fluctuated from 434 to 792 over this time frame. This fluctuation is normal for sea turtle populations as females do not reproduce every year (Ceriani et al., 2019). The number of leatherback sea turtle nests in 2020

(467) was lower than the average of 548 nests for this six-year period, but was not significantly lower than previous years (Fig. 2a).

We expected to find a lower encounter rate of nesting turtles during the COVID-19 lockdown as only one research station was actively operating. However, assistants encountered a higher percentage of nesting turtles in 2020 (X ≥ 91.2% of nesting females sighted in respect to total nests from 2015 to 2019). Thus, they were able to relocate many nests despite fewer night censuses and protect a larger number of eggs from tide inundation and poaching (Fig. 2b). Our hypothesis that the encounter rate of nesting turtles would be negatively impacted by fewer night censuses and reduced financial resources was not supported.

3.2. Leatherback poaching rate

Long-term conservation efforts in Pacuare Reserve have successfully reduced poaching rates. Reduced security, fewer researchers on the beach at night and the decision to close the north station may account for the fact that the number of nests poached quadrupled in 2020 (20) compared to 2019 (5) and 2018 (7). However, a similar number of poached nests was seen in 2017 (18) and 2016 (19). The highest number of leatherback sea turtle nests poached was observed in 2015 (26). Overall, Fig. 3 reveals a decreasing trend line on poaching rates.

Poaching has never occurred within the hatchery since its implementation in 2018, and is still considered a safe area for relocation near the station. The 2020 season marked the first construction of a relocation zone next to the hatchery. This also proved to be a suitable location as zero nests were poached from this zone. All poached nests during the COVID-19 lockdown were located on the north and central portion of the beach, 2 to 5.7 km away from the south station.

Fig. 3 supports our hypothesis that poaching of leatherback sea turtle nests would rise during the COVID-19 lockdown due to the decrease in the number of night censuses.

3.3. Leatherback nest management and hatching success

Hatching success was analyzed as an indicator of nest management decisions. From 2015 to 2017, leatherback nests were either left *in situ* or relocated along the beach. In 2018 and 2019, nests were also relocated to a hatchery at the north or south station. In 2020, only the south station and southern hatchery were in operation and a new relocation zone was created bordering the hatchery.

We found that nests left *in situ* had higher hatching success rates than relocated nests from 2015 through 2017; however, nests vulnerable to poaching and erosion continued to be relocated. In contrast, from 2018 to 2020, nests relocated along the beach and in the hatchery had more successful hatch rates than clutches left *in situ*. We observed an increasing trend for hatching success in the hatchery which rose from 62% in 2018 to 69% in 2020. The creation of a relocation zone in 2020 resulted in an exceptionally high hatching success rate of 61%, only marginally lower than that of the hatcheries from 2018 to 2020 (Fig. 4).

In previous years, the relocation distance never exceeded 3 km. However, in 2020, 60% of clutches were moved farther than 3 km for relocation to the southern hatchery or the relocation zone. COVID-19 lockdown decisions led to the transportation of clutches up to 5.7 km to minimize the risk of poaching and tide inundation. Fig. 5 demonstrates that eggs transported a farther distance for relocation (and consequently exposed to outdoor conditions longer) possessed a lower hatching rate, which decreased as the relocation distance increased ($F_{2,259} = 5.25$, $p < 0.01$). Despite this negative relationship, translocation still increased the overall hatching rate for clutches when considering the significantly lower success of *in situ* nests.

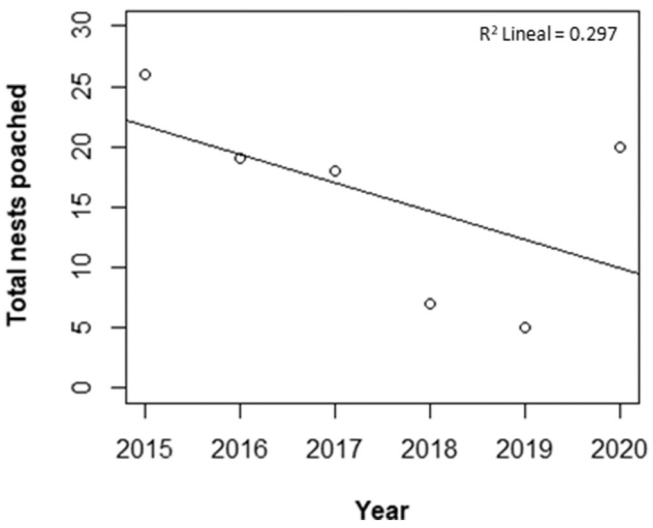

Fig. 3. Total leatherback sea turtle (*Dermochelys coriacea*) nests poached per year (2015–2020) in Pacuare Reserve.

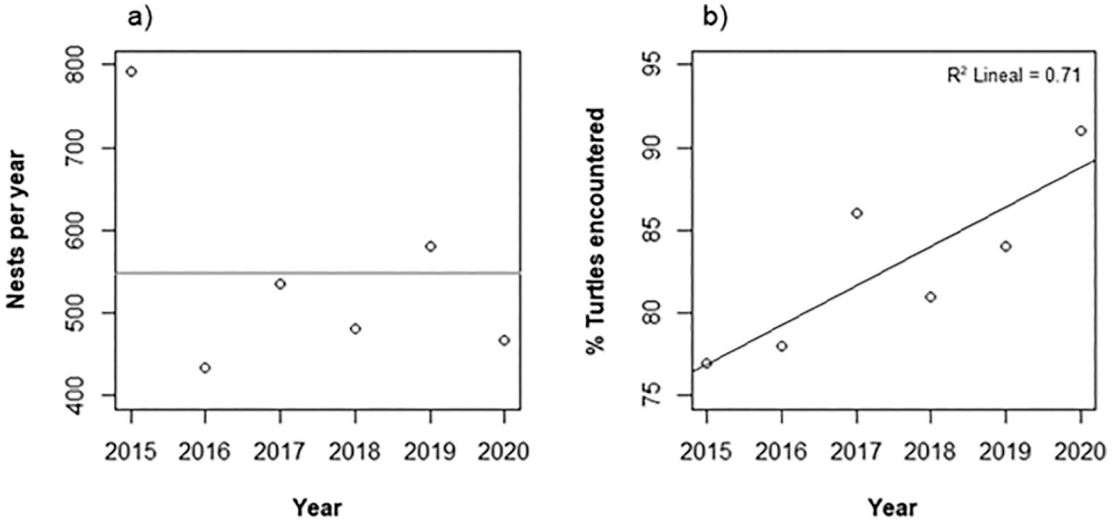

Fig. 2. a) Total leatherback sea turtle (*Dermochelys coriacea*) nests recorded per year (2015–2020) in Pacuare Reserve with a line showing the average for this six-year period. b) Percentage of nesting leatherback sea turtles encountered per year in Pacuare Reserve. Note: y-axis does not start at zero.

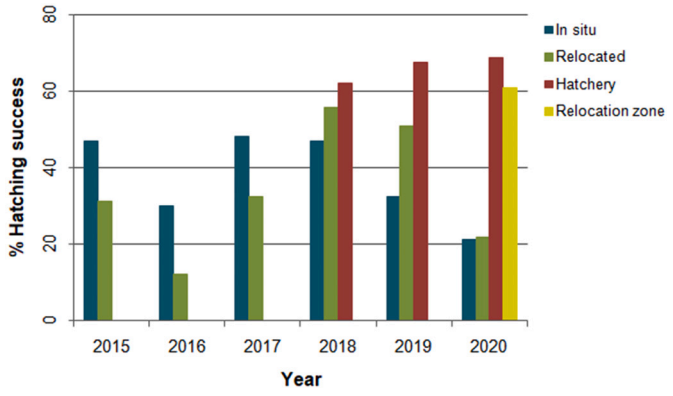

Fig. 4. Leatherback sea turtle (*Dermochelys coriacea*) hatching success in *in situ* nests, nests relocated along the beach, in the hatchery and designated relocation zone per year (2015–2020) in Pacuare Reserve.

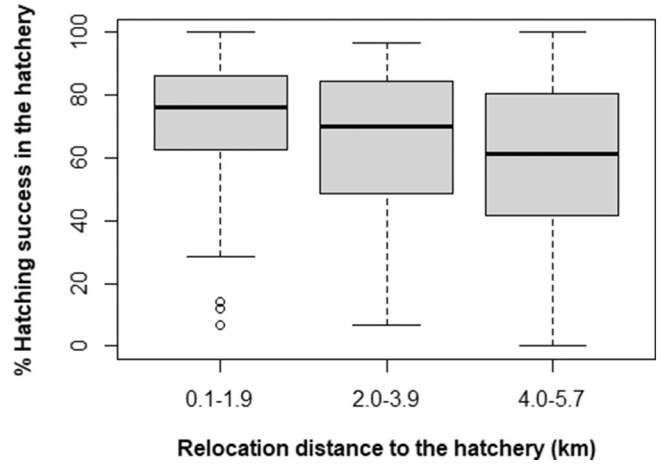

Fig. 5. Leatherback sea turtle (*Dermochelys coriacea*) hatching success in the southern hatchery of Pacuare Reserve in 2020, related to the distance that the nests were relocated.

3.4. Pacuare Reserve students and visitors

In 2020, only 3% (39) of the expected 1328 students were received. The COVID-19 lockdown led to the cancellation of all but two visiting groups who arrived before the borders closed. Table 1 demonstrates that the number of total visitors in 2020 dropped significantly by 76% from 2019.

4. Discussion

4.1. Effects of COVID-19 lockdown on night censuses, daytime activities and environmental education

Due to the COVID-19 lockdown, a reduction in financial resources from lack of visitors forced Pacuare Reserve to modify the sea turtle monitoring protocols and operate from only one of two research stations.

In 2020, only three nightly censuses were conducted from the south station in contrast to the six censuses conducted in previous years (three from each station). The monitoring distance increased by 100% as censuses leaving from the south station were responsible for monitoring both the northern and southern sections of the beach (from post 0 to 57 or 5.7 km each way). The typical 4 hour night census increased, lasting up to 8 h on nights with a lot of activity. For most of 2020, monitoring censuses were conducted by two research assistants because no more student groups visited the reserve after March 11th, 2020. The morning census doubled in both distance and time from 5.7 to 11.4 km and from 2 to 4 h.

Research assistants were required to perform additional responsibilities unrelated to fieldwork such as cleaning and fundraising to maintain the station and compensate for the lack of personnel. In a regular season, the research assistants are responsible for assisting the researcher in a number of tasks that fulfill 1 FTE of 36 h per week (6 h per day/6 days a week). During the 2020 COVID-19 season, research assistants fulfilled 2 FTE (12 h per day/6 days a week). Resulting fatigue from reduced resting time during the day and night contributed to 50% of the research assistants leaving the project within the first 3.5 months.

Governmental travel restrictions (directive MINISTERIO DE AMBIENTE Y ENERGÍA N° 0003-2020, from April 15th to July 1st) posed a further challenge for research assistants and staff who were obligated to remain at Pacuare Reserve on their days off.

Despite receiving fewer nests than previous years and monitoring an increased distance, researchers achieved the highest encounter rate of leatherback sea turtles in 2020 out of all six seasons. We attribute this increase to faster data collection by researchers. In 2020, assistants left sea turtles immediately after data collection was completed in order to survey both sections of beach and continue to find females in early nesting stages. In the past, assistants frequently remained with the sea turtles until they returned to the ocean in order to educate student groups on the nesting process.

Students in Pacuare Reserve learn about the effects of human activities on the marine ecosystem and participate in night census data collection by assisting with measuring sea turtles and other tasks. These experiences cultivate a sense of environmental responsibility among participants (Graham, 2003). When youth are exposed to nature through residential science programs, they demonstrate more positive attitudes towards the environment and more concern towards climate change (Gray, 2003). Increased knowledge and motivation can lead to key behavioral changes related to environmental responsibility up to five years after program participation, positively impacting conservation (Collins et al., 2020).

Due to the absence of student and visitor participation in night censuses during the COVID-19 lockdown, environmental education was no longer a responsibility for the research assistants during monitoring. Spending less time with each turtle benefited monitoring by minimizing the number of turtles missed, but sacrificed potential learning opportunities to further observe animal behavior.

4.2. Effects of 2020 COVID-19 lockdown on leatherback sea turtle nesting behavior

The COVID-19 lockdown's reduction in global tourism has generated a positive impact on natural wildlife behaviors as more wildlife has been spotted in populated areas across the globe (Corlett et al., 2020; Gardner, 2020). Pacuare Reserve has not observed a difference in regards to wildlife sightings due to its pre-established limited ecotourism which ensures minimal stress levels on wildlife year-round.

Pacuare Reserve's leatherback sea turtle nesting numbers have remained relatively stable, taking into account natural fluctuations. While nest counts are commonly used to estimate population trends, they represent only a fraction of the population. As a species that

Table 1
Ecology Project International (EPI) students and other visitors in Pacuare Reserve from 2017 (EPI's first year as administrator) to 2020.

	Year			
	2017	2018	2019	2020
EPI students	408	408	556	39
Other visitors	311	705	803	288
Total visitors	719	1113	1359	327

requires decades to reach sexual maturity, nest counts reflect prior events in the water or on the nesting beach such as threats or previously established conservation measures, rather than current situations (Ceriani et al., 2019). Thus, nesting behavior was not influenced by the COVID-19 lockdown; 2020 marked the lowest number of nests since 2017.

4.3. Effects of 2020 COVID-19 lockdown on poaching

A significant loss in revenue due to reduced visitation in wilderness areas often leads to weakened surveillance for wildlife, making these areas more vulnerable to poaching and resource exploitation (Buckley, 2020). Protected places such as Pacuare Reserve cannot maintain anti-poaching surveillance and other management strategies without income from tourism (Gardner, 2020).

While Costa Rican law (Law 8325 and Law 7317) prohibits the harvest of sea turtles and their eggs (the only exception is the collection of olive ridley sea turtles (*Lepidochelys olivacea*) eggs following strict regulations in Ostional); poaching remains an ongoing problem (Le Guern, 2011). Pacuare Reserve has employed security guards who are on duty from 18:00 to 06:00 at each research station. 2020 was an exception, as only one security guard watched the south station from 22:00 to 04:00. The north station was not protected by a guard and it is likely that poachers accessed the beach from the northern border.

Extended night censuses ensured maximum protection of the eggs as the majority of nests (63%) were relocated either to the hatchery (41.5%) or to the relocation zone (21.4%) near the south station once the hatchery was filled. The efforts of the research assistants who carried the eggs up to 5.7 km in order for relocation likely prevented additional poaching from occurring during the COVID-19 lockdown. While there was a notable increase in poaching from 2019, the number remained similar to the amount of nests poached in 2016 and 2017.

4.4. Effects of 2020 COVID-19 lockdown on nest management and hatching success

Several factors contribute to the consistently high hatching success rate in the hatchery. It is a more controlled environment for egg incubation with a mesh fence and individual mesh baskets to minimize predation. Shade protects the nests from extremely high temperatures. The sand in this zone is thoroughly sifted in order to remove debris and other vegetation which may harm egg development (Quesada, 2017).

Translocation to the hatchery aims to improve the likelihood of survival for otherwise 'doomed eggs' at risk of poaching or tide inundation (Sieg et al., 2011). Hatching trends demonstrate that the hatchery is in fact increasing clutch survival in comparison to the success of *in situ* nests which declined steadily from 2018. In fact, the hatching success rate in 2020 was the highest ever for nests that were relocated to the hatchery. Additional nests successfully hatched in the new relocation zone.

Further analysis is needed to determine why the decline in *in situ* hatching success is occurring. Leatherback clutches are characterized by low hatching success despite high fertility rates which implies the role of factors such as developmental genetics, maternal identity and nest environment (Garrett et al., 2010; Tiwari et al., 2011).

Our findings in regard to hatching success contradict a previous study (Chan et al., 1985) who argued that leatherback sea turtle eggs can endure 'rough handling' up to 5 h after oviposition without a decline in hatch rate. We suspect that the delay in egg relocation and prolonged outdoor exposure during transport of up to 5.7 km may have reduced the hatch rate (Eckert and Eckert, 1990). Whenever possible, eggs should be reburied without delay (Sieg et al., 2011).

We consider previous studies of hatcheries that augmented hatchling production overall, but observed a decreased hatching success of hatchery clutches when compared to *in situ* (Eckert and Eckert, 1990; Sieg et al., 2011). If eggs are transported and reburied carefully, hatchery translocation is an effective method to boost hatchling production (Eckert and Eckert, 1990). Given these findings, we advocate that this conservation strategy should continue to be used with caution, taking into consideration all threats specific to each nesting beach (Sieg et al., 2011).

Another factor that may have influenced the hatch rate of the relocation zone and hatchery clutches was the number of times that eggs were reburied. Relocated eggs are typically re-buried once when they are moved to a safer sector. Due to logistical challenges in 2020, a number of hatchery and relocation zone clutches were subjected to two reburials and underwent a subsequent temperature change as a result. Previous research suggests that the physical act of moving the eggs does not harm early embryonic stages if eggs are re-buried immediately. However, damage during a 'critical period' of extra-embryonic membrane formation beginning from 48 h to 2.5 weeks is fatal for early-stage and pre-carapace embryos (Eckert and Eckert, 1990).

Nest environment conditions in particular are important to consider during egg relocation. Studies have shown that developing embryos have the ability to collectively affect their own environment as nest gas concentrations and temperatures vary widely during embryonic development. Leatherback embryos have demonstrated developmental sensitivity to high levels of carbon dioxide, low oxygen levels and nest temperature (Garrett et al., 2010). However, the interactions between the hydric, gaseous and temperature conditions that embryos are exposed to create an insulating effect by which several hours or more may pass before alterations in nest conditions influence the embryos. Thus, external events such as the environmental conditions of the beach or an additional reburial do not immediately impact the embryos. It is difficult to predict exactly when modifications to nest conditions begin to negatively affect embryos as the timing of developmental stages varies naturally due to the environment (Miller et al., 2017).

However, determining hatching success along with the developmental stage of embryos in unhatched eggs can help identify mortality factors in the hatchery or on the beach when combined with beach temperature and incubation duration. The staging key created by Miller et al. (2017) can be used to estimate the time of death and combined with recorded weather conditions to identify likely causes of mortality. In future investigations, this can help us better understand the impacts of egg relocation as a conservation strategy and its potential effects on embryonic development.

5. Conclusions

The COVID-19 lockdown brought significant changes and challenges to Pacuare Reserve's leatherback sea turtle conservation efforts. We proposed that the loss of visitors, reduced staff and night censuses, and reduced financial resources negatively affected conservation in terms of fewer leatherback sea turtles encountered during night surveys, increased poaching of nests, and less effective nest management measured by hatching success.

Despite fewer censuses per night, fewer total nests and a heavier workload during the COVID-19 lockdown, the effort of the research assistants culminated in a much higher encounter rate of turtles seen. Our findings indicate that nest management decisions in 2020 vastly benefited species conservation as hatching success notably increased for nests moved to a newly constructed relocation zone, which outweighed the negative correlation detected between the relocation distance (related to outdoor exposure) and hatching success. There was an increase in poaching in 2020, but the number of poached nests was still within the range observed in previous seasons.

Our hypothesis that the loss of visitors, the reduced staff and beach presence, and reduced financial resources negatively affected leatherback sea turtle conservation was incorrect. We conclude that monitoring efforts were successful during the COVID-19 lockdown. However, environmental education, one of EPI's primary objectives, was not accomplished to its full extent. We highlight the gravity of these

numbers as outdoor science education remains an essential component of Pacuare Reserve's conservation efforts.

While the overall results of this study are encouraging for sea turtle conservation outcomes, our evaluation of monitoring efforts is limited to a single nesting beach. Combining data sets from other projects is needed in order to form a more complete picture of sea turtle nesting trends, challenges and successes of ongoing research during the COVID-19 lockdown (Rutz et al., 2020).

Declaration of competing interest

The authors declare that they have no competing interests.

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