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Tracing the origins of sea turtle eggs in the markets of Costa Rica

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Abstract

Unsustainable wildlife trade is a major contributor to biodiversity loss; however, trade regulations have failed to prevent the decline of high-profile species. Where wildlife is traded legally, opportunities exist to launder protected species through legal channels. The legal commercialization of olive ridley sea turtle eggs from Ostional, Costa Rica, has been criticized with some suggesting that the legal trade stimulates illegal extraction and sale of eggs. We aimed to identify whether the traceability rules, under which the Ostional project operates, were suitably robust. We surveyed markets across Costa Rica, by purchasing openly available sea turtle eggs and recording qualitative and quantitative data at the point of sale. We found that 378 (80%) of turtle eggs openly sold in the market were from olive ridley sea turtles. Green ($n = 5$) and leatherback ($n = 6$) turtle eggs were only on offer on three occasions, but no vendor referred to Ostional. Vendors frequently breached trade regulations, which appeared to be due to these regulations misaligning with consumer demand. Although the Ostional traceability rules are regularly flouted, we found no evidence that Ostional is being used as a cover to sell eggs from other turtle species.

KEYWORDS

ADIO, certification, *Chelonia mydas*, illegal trade, laundering, *Lepidochelys olivacea*, livelihoods, Ostional, sustainable use, wildlife trade

1 | INTRODUCTION

Major biodiversity losses can partly be attributed to unsustainable wildlife trade (Lyons & Natusch, 2011; Rosen & Smith, 2010). Often countries rich in natural resources are the most impoverished and poorly equipped to prioritize conservation (Damania & Bulte, 2007). Wildlife trade regulations have failed to reduce the rate of decline for numerous high-profile species (Roe, 2002), and opportunities to launder illegal wildlife exist wherever there are legal trade routes (van Uhm, 2016). A legal trade can be used to reduce illegal extraction if (1) having a legal supply does not increase demand; (2) the legal product is a suitable substitute; and (3) it is more cost effective to supply the product legally than illegally, meaning laundering can be circumvented (Tensen, 2016). However, opportunities exist to launder wildlife at different stages of the trade chain. One of the most high-profile debates concerning wildlife laundering centers on a future legal trade in rhino horn. If a legal market were to be opened for sustainably sourced rhino horn, a chief concern is the difficulty in identifying the source of the horn. This could potentially open opportunities to launder illegally sourced products and stimulate illegal take (Eikelboom et al., 2020). Each side of this debate has compelling theoretical arguments, but the debate lacks empirical data to inform policy. Here, we focus on the legal trade of turtle eggs from Ostional, Costa Rica, as an example of wildlife utilization that allows for the further examination of the issue of wildlife laundering.

Of the seven species of extant sea turtle, five nest on Costa Rica's beaches: green (*Chelonia mydas*), olive ridley (*Lepidochelys olivacea*), leatherback (*Dermochelys coriacea*) and hawksbill (*Eretmochelys imbricata*), and occasionally loggerhead turtle (*Caretta caretta*) nesting events occur. Sea turtle eggs are white soft-shelled spheres that vary in size according to the species (Pritchard & Mortimer, 1999). Under the International Union for Conservation of Nature (IUCN) Red List, all turtle species that nest in Costa Rica are vulnerable to extinction, from the threatened olive ridley to the critically endangered hawksbill turtle (IUCN, 2019). Anthropogenic threats to turtles at sea include plastic pollution, fisheries by-catch, and entanglement in discarded fishing gear (Duncan et al., 2017). A significant threat to sea turtles on land is the illegal take of their eggs, meat, and shell (Pheasey et al., 2023). Sea turtle eggs are a traditional food source in Costa Rica, particularly in the Caribbean where the consumption of turtles is culturally ingrained (Campbell, 2007). Despite being illegal under Wildlife Conservation law #4551 since 1966, illegal take still takes place to a degree that warrants most nesting beaches needing volunteer patrols to safeguard the nesting females and their nests. Few households rely on sea turtle eggs to fulfill protein requirements, and they are largely consumed as bar snacks or street food by the locals (Arauz Almengor et al., 2001; Pheasey et al., 2020).

Costa Rica is home to two globally important sea turtle nesting rookeries. On the Caribbean coast, Tortuguero hosts the largest green turtle aggregation in the Atlantic Basin (Campbell, 2007; Troëng & Rankin, 2005), and Ostional, in the Pacific, is one of the most important nesting sites for olive ridley turtles (Valverde et al., 2012). All turtles are solitary nesters; however, ridley turtles (olive and kemps [*L. kempii*]) also exhibit synchronized mass nesting events known as *arribadas* (Spotila, 2004). *Arribadas* can comprise hundreds or thousands of females nesting in unison over 2–10 days, with Ostional being one of the largest current *arribada* beaches (Eckrich & Owens, 1995; Valverde et al., 2012). In Ostional, these events generally occur monthly with a seasonal peak in nesting females between September and December. Due to the concentration of turtles nesting over several days, the destruction of nests by turtles excavating existing nests is significant (Cornelius et al., 1991). Nests laid during the first three nights of an *arribada* are most likely destroyed by predators or turtles subsequently excavating existing nests. The microbial decomposition of damaged eggs and presence of pathogens in the sand reduce hatching success of incubating nests from 90% on solitary beaches, to below 15% at Ostional (Bezy et al., 2020; Cornelius et al., 1991; Valverde, 1999). Due to the volume of eggs wasted during the first nights of an *arribada*, the Ostional community are permitted to harvest and sell doomed eggs for a domestic trade. The controlled legal harvest and commercialization of olive ridley eggs is permitted under the rationale that the harvest only removes doomed eggs. This removal theoretically promotes a healthier beach, with increased hatchling output, by reducing the risk of infection of incubating eggs by pathogens from adjacent dead eggs (Campbell, 1998; Cornelius et al., 1991).

Although critics voice concerns over the laundering potential, the commercialization of the eggs supports the Ostional community and is undeniably a socioeconomic success (Campbell, 1998). In exchange, the community protects the turtles by keeping the beach clear of debris, escorting hatchlings to sea when they emerge from nests, providing overnight security against illegal take, and controlling the number of tourists who come to witness an *arribada* (Campbell et al., 2007). The harvest and conservation work are managed by ADIO (Asociación de Desarrollo Integral de Ostional) who report to MINAE (the Costa Rican Ministry of Environment). Costa Rica is a signatory to the Inter-American Convention for the Protection and Conservation of Sea Turtles, which recognizes the commercialization of eggs from Ostional as an exception to an otherwise complete ban on turtle trade and consumption in Costa Rica. The harvest of eggs from Ostional is permitted under several conditions, one of which is ensuring the eggs are traceable when sold nationwide. The Ministry of Fisheries (INCOPESCA) and National Animal Health Service (SENASA) issue permits to transport and sell Ostional eggs, which is legally binding under Executive Decree #28203 (1999), specifically written for the Ostional project. These permits are part of the traceability scheme detailed below.

All sea turtle species' eggs are morphologically similar, with size being the only distinguishing feature by which species can be visually identified. This is confounded further by overlap in size of eggs between some species (Moore et al., 2003; Pritchard & Mortimer, 1999). For this reason, there has long been the concern that the

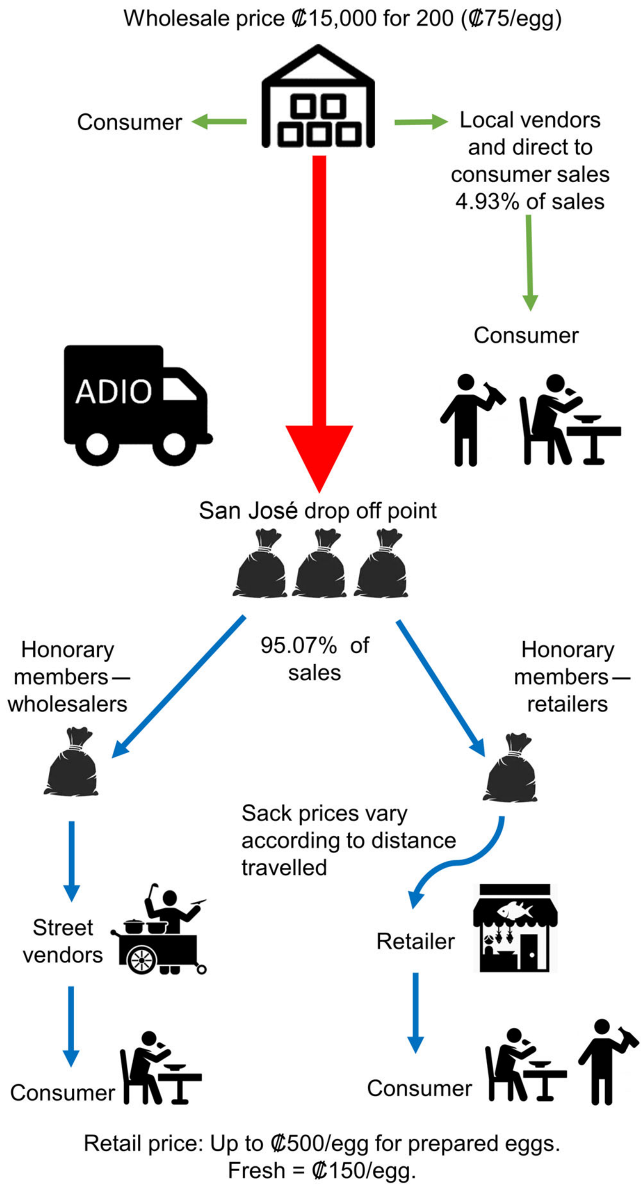

FIGURE 1 The-retail chain (adapted from ADIO annual reports (Lobo-Glez, 2013–2018)).

sale of Ostional eggs has the potential to enable the laundering of illegally extracted eggs through open trade channels. Historically, ADIO sold eggs in sacks of 200 loose eggs, closed with a zip tie. Once open, there was no way to restrict the refilling of Ostional sacks with illicit eggs. In response, under Article IV, 3a and b, the Inter-American Convention for the Protection and Conservation of Sea Turtles requested that Ostional be accountable for the sale and movement of the eggs. This resulted in a 5-year management plan with traceability rules introduced in 2017 (MINAE & SINAC, 2017). These rules require ADIO to sell eggs in smaller heat-sealed bags embossed with the ADIO logo. Initially, the smaller bags contained 10 eggs; however, this was increased to 20 eggs in February 2018. ADIO packages 10 of these smaller bags in sacks, which contain a total of 200 eggs, and sells each sack for €15,000 to licensed intermediaries. These intermediaries, known as *Honorarios*, hold permits to transport eggs across the country and resell the eggs to local vendors. ADIO is reliant on *Honorarios* to sell eggs on their behalf, with 95% of sales via these middlemen and <5% comprising local sales in Ostional (Lobo-Glez, 2013-2018) (Figure 1). ADIO are required to number and date all egg packages that leave Ostional. A receipt of purchase accompanies eggs with the corresponding number. Being in possession of illegal eggs is an offense under the Costa Rican Law #8325. However, contradicting this, it is also not illegal to purchase turtle eggs, regardless of the species.

Despite the traceability rules, many vendors sell turtle eggs loose, in unmarked packaging or prepare eggs for sale—either boiled or cracked raw into a chili sauce called *sangrita*. By removing eggs from the legal packaging, they are undermining the traceability scheme and with it the assurance the eggs are legally sourced. In Costa Rica, olive ridley turtles only nest on the Pacific coast and exhibit low natal fidelity (Bowen & Karl, 2007), nesting both solitarily and in *arribadas* (Plotkin et al., 1997). For these reasons, it is not currently possible to trace an olive ridley egg back to its natal beach and therefore not possible to confirm if an olive ridley turtle egg found in the market is specifically from Ostional.

Before the introduction of the current traceability rules, the commercialization of eggs from Ostional provoked widespread criticism due to the laundering potential it offers and fear the trade stimulates illegal take. This research tested the validity of these concerns by addressing the question: how effective is the ADIO traceability scheme? This was undertaken by (1) looking for flagrant rule breaking in the form of illegal species' eggs sold under the ADIO banner and (2) making observations at the point of sale.

2 | METHODS

The School of Anthropology and Conservation's Research Ethics Advisory Group (University of Kent) approved this research (Ref. No. 0381617c).

We recruited local research assistants, who were over the age of 18, to purchase turtle eggs. They were aware of the purpose of the research, provided signed consent, and were given financial compensation for their time. Under Costa Rica law #8325, it is illegal to interfere with sea turtle nests, transport eggs, or sell uncertified turtle eggs. However, it is not illegal to purchase turtle eggs, regardless of the species. As this research only involved

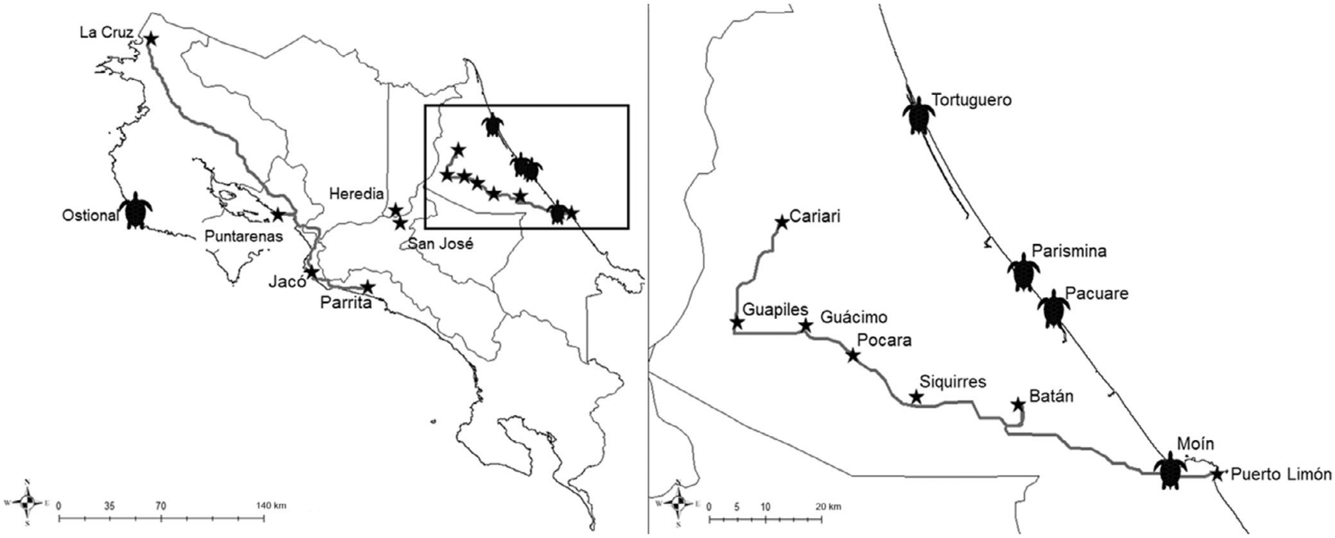

FIGURE 2 Map of Costa Rica showing egg buying routes and destinations (stars). Beaches with high abundance of nesting female turtles are depicted by the turtle symbol.

purchasing turtle eggs, no permits were required. The Centro de Investigación en Biología Celular y Molecular (CIBCM) at the University of Costa Rica is permitted to analyze genetic material from any organism (in situ or ex situ). Permission for this project titled "Evaluar a qué especies pertenecen huevos de tortugas marinas en el comercio legal de Costa Rica" was issued to the CIBCM by the Comisión Institucional de Biodiversidad, Resolución #201, (Ref. No. VI-801-C0115).

2.1 | Study sites

Sea turtle eggs are available to buy from mobile street vendors, bars and canteens, market, and street stalls. The Central Valley serves as a major transport hub for legal eggs arriving from Ostional, for distribution throughout the region and to the Caribbean. In the Central Valley, most of our surveys took place in Downtown San José, the capital of Costa Rica, with a few opportunistic surveys in Heredia. Puerto Limón housed green turtle abattoirs until the government outlawed the practice in the 1970s but remains a hotspot for illegal trafficking of turtle meat and eggs. We conducted monthly egg buying tours throughout Limón province where we purchased eggs from Guapiles, Cariari, Guácimo, Pocara, Siquirres, Batán, and Puerto Limón (Figure 2). Cariari is the nearest town to Tortuguero, and Siquirres is near the beaches Parismina and Pacuare. The latter both receive a high number of leatherback turtles nesting each season. Puerto Limón, the regional capital, is an economically deprived city close to Moín, another large leatherback turtle nesting beach. The city houses an outdoor market with a row of fishmongers and seafood stalls. Puntarenas is a port city located on a narrow peninsular on the Pacific coast and the main landing dock for pelagic fish on this coast of Costa Rica (O'Bryhim et al., 2017). In Puntarenas, there is a market near the docks which, although small, houses a high number of fishmongers offering turtle eggs.

We purchased turtle eggs between September 2017 and November 2018 in three regions of Costa Rica: The Central Valley, Limón Province in the Caribbean, and the northern Pacific coast. In addition, we surveyed bars and canteens along the Inter-American highway, between Puntarenas and La Cruz, over 2 days in January 2018. All surveys were timed to coincide with seasonal nesting events for species other than olive ridley turtles and therefore increase the chance of detecting illegal eggs. In addition to regular surveys, we utilized any opportunity to purchase turtle eggs and included these samples in our dataset.

2.2 | Market surveys

We recruited 16 local research assistants who had previously worked for us and were trained to undertake the survey. These assistants purchased eggs that were openly available at the study sites. The criterion for purchasing eggs was anything other than a heat-sealed bag embossed with the ADIO logo (hereafter ADIO bags)—unless the bag contained eggs that were uncharacteristically large—this included cooked eggs and eggs in *sangrita*. ADIO bags that had been opened, torn and/or retied with a knot, or contained the incorrect denomination of eggs (other than 10 or 20 per bag) were classified as misused. When buying eggs, the researcher asked the vendor an open question about where the eggs were from (without mentioning Ostional). When buying unpackaged shelled eggs, the research assistants also requested the vendor select the largest eggs. This increased the chances of detecting species' eggs other than olive ridley (hereafter *illegal species*). We sampled as many vendors as possible and made monthly repeat visits when the opportunities arose; however, this was limited to permanent establishments/pitches and chance re-encounters with mobile vendors.

The following data were covertly recorded during the purchase: date, location, type of vendor (mobile, market stall, bar/canteen), stall name (if applicable), information on any signage to suggest eggs were from Ostional, if the eggs were on display or hidden from view, or if not on display, how the researcher became aware there were eggs for sale (heard/saw mobile vendors or poster/menu etc.), type of egg (cooked, fresh or in *sangrita*), the price, and quantity of eggs being sold. We did not ask questions about permits due to the possible sensitivity of this type of question and because the researchers were unlikely to recognize counterfeit permits. It was not always possible to collect complete data due to the vendor's reluctance to answer questions, or there were occasions when we did not purchase eggs but recorded other data, for example, eggs were only for consumption on the premises or the vendor was out of stock. Pertinent comments made by vendors were also noted.

Once purchased, we photographed the eggs and measured them using calipers. We took samples of yolk, albumen, and shell with membrane using scissors, forceps, and single-use pipettes. We cleaned instruments between samples using alcohol swabs. We stored samples in Eppendorf tubes in 96% ethanol.

2.3 | Market survey analysis

During the study period, ADIO were not able to use heat-sealed printed bags for two *arribadas*. This was due to an administration error during a change in board of directors and on a separate occasion, the bag heat-sealing machine was not working. This explained the misuse of 25 bags, and these were removed from the analysis. On three occasions, we identified vendors selling unmarked bags of eggs next to ADIO bags, which we also classified as misused. A further two data points were removed from the analysis as they were ad-hoc purchases without accompanying purchase data. We considered eggs advertised or on menus to be *on display*. To gain an understanding of patterns in sales, we compared the number and type of vendors (bar/restaurant, market stall, or mobile) with the type of eggs they sell (fresh, cooked, or in *sangrita*) using a Pearson's chi-squared test of association. In February 2018, ADIO increased the number of eggs per bag from 10 to 20 eggs. We noted the number of eggs we found in ADIO bags and whether they were misused (open) or not. Finally, we used a one-sample *t*-test to test the hypothesis that vendors were selling eggs outside legal packaging at a significantly higher price than ₡150/egg. This price appeared to be the unofficial cap that consumers would pay for eggs sold in ADIO bags.

2.4 | Species identification

We used two approaches to identify species and compared our findings to published material. We used size (mm diameter) of eggs, compared with Pritchard and Mortimer (1999), and diagnostic restriction fragment length polymorphism for species identification, as per Moore et al. (2003) (Table 1 columns a and b). To establish if the boiling process altered eggs size, we purchased two bags of ADIO certified eggs ($n = 39$). Each egg was measured to the nearest 0.1 mm using digital calipers, boiled for 12 min (as per the recipe used by the street vendors [pers. comm.]) and then remeasured. A Mann–Whitney *U* test was used to compare the size of eggs before and after boiling.

2.5 | DNA extraction and polymerase chain reaction

All genetic analysis was undertaken by the Centro de Investigación en Biología Celular y Molecular (CIBCM) at the University of Costa Rica, using their protocols and methods. We extracted whole DNA from approximately 50 mg of egg yolk following a modified salt-extraction protocol (Aljanabi & Martinez, 1997). For cellular lysis, 20 μL of Proteinase K (20 mg/mL) was added to 350 μL of extraction buffer (100 mM NaCl, 50 mM Tris–HCl, 1% SDS, %0 mM EDTA, pH 8.0) and incubated overnight at 55°C. To assign species, we performed PCRs (polymerase chain reaction) to amplify 875–876 bp fragments of the cytochrome b region, using the primers designed for restriction fragment length polymorphism (RFLP) species identification (Moore et al., 2003): long-Glu-L (5′-TGATATGAAAAACCATCGTTG-3′) and long-Cb3-H (5′-GGCAAATAGGAARTATCATTC-3′). PCRs were conducted in 25 μL reactions containing 2 μL of DNA template, 13.4 μL H_2O, 2.5 μL of Buffer, 2 μL $MgCl_2$, 1.3 μL dNTP, 1.8 μL of each primer, and 0.2 μL Taq polymerase.

TABLE 1 Species identification criteria.

Species common name	Species Latin name	Published species identification criteria a Diameter egg size (mm) IUCN[a]	 b Expected base-pair fragment size[b]	 c Mean diameter egg size (mm) our data
Leatherback	*Dermochelys coriacea*	51–55	818	52.1 (50.2–53.8[c])
Green Atlantic population	*Chelonia mydas*	40–46	189, 226, 460	44.0 ($n = 1$)
Green Pacific population	*C. mydas*	40–45	72, 154, 189, 460	n/a
Hawksbill	*Eretmochelys imbricata*	32–36	58, 154, 663	n/a
Loggerhead	*Caretta caretta*	39–43	58, 348, 469	n/a
Olive ridley	*Lepidochelys olivacea*	37–42	58, 321, 496	38.9 (35.0–42.7)

Sources: [a](Pritchard and Mortimer 1999), [b](Moore et al. 2003), [c]not identified using genetic analysis. n/a = not applicable.

For all reactions, the PCR protocol included an initial denaturation step at 94°C for 2 min, followed by 30 cycles of 50 s denaturation at 94°C, 30 s annealing step at 50°C allowing the primers to bind to the complementary sequences, and a 60 s final extension at 72°C for the *Taq's* synthesis of new chains. PCRs were carried out in Applied Biosystems® thermocycler. The PCR products were confirmed visually in 2% agarose gel electrophoresis (90 V, 45 min) stained with GelRed®.

2.6 | Restriction enzyme digestion

Fragments were digested with the restriction enzyme Alu I, which recognizes 5′-AG^CT-3′ and produces species-diagnostic RFLPs for species identification (Moore et al., 2003). This restriction enzyme cuts fragments of 156, 168, 228, 417, 471, 498, and 818 bp, and depending on the size of the DNA fragments obtained after the enzymatic digestion, which will correspond to the autapomorphic restriction sites of each species, the identification of the species nesting in Costa Rica is possible (Table 1).

During our pilot study, it was established that the yolk contained the most DNA material and albumin the least. In addition, we used chi-squared to test whether preparation method affected amplification. We created a list of size ranges for each species we identified using DNA analysis (Table 1 column c), this varied slightly to the IUCN size ranges. In cases where we did not extract DNA from an egg, we used the measurement from our results to identify the species from which the egg originated. In ambiguous cases where there was a size overlap between possible species, we considered variables such as nesting events and geography to allocate an egg to a species. For example, eggs small enough to be hawksbill, but purchased in February outside the hawksbill nesting season, were designated as from olive ridley turtles. All statistical analysis was undertaken in RStudio 1.2.1335 running packages: gmodels, MASS ggpubr, using RStudio 1.2.1335 (R Core Team, 2019).

3 | RESULTS

3.1 | Market surveys

We visited vendors and businesses on 164 occasions on 31 days between September 2017 and October 2018. We purchased 472 eggs on 131 of these visits. The number of eggs purchased on each occasion varied from 1 to 13 eggs, according to the vendor's pack sizes. We identified 92 individual vendors and businesses selling uncertified eggs. Surveys were undertaken monthly, which gave vendors enough time to exhaust and replenish their stock. Vendors included 30 bars that had catering facilities on the premises, 4 catering outlets such as canteens that did not additionally sell alcohol, 30 mobile vendors, 28 shops and market stalls; including a toy shop that also sold turtle eggs during peak *arribada* season. There was a significant difference in the type of eggs sold by different types of vendor. Bars tended to sell eggs in *sangrita* (25.6%), stalls mainly sold fresh eggs (23.3%), and mobile vendors (24.4%) sold cooked eggs ($\chi^2[4] = 108.5$, $p < .001$) (Figure 3).

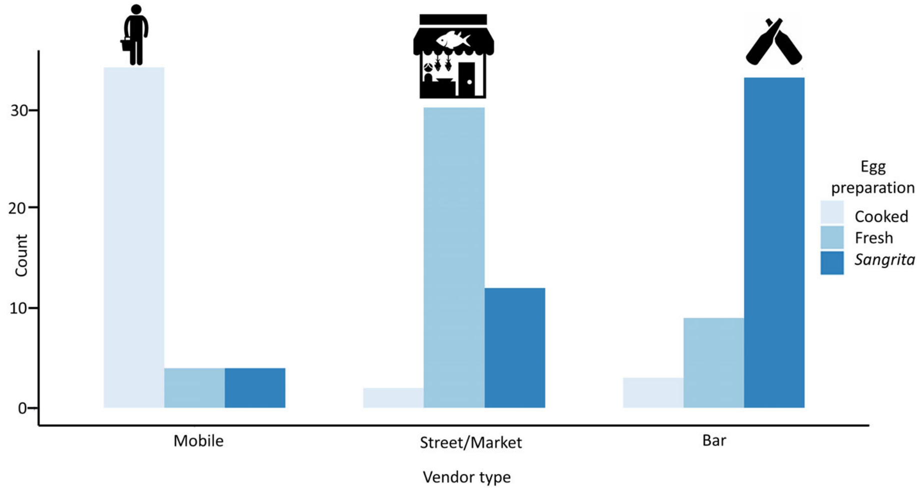

FIGURE 3 Frequency of availability of different types of egg purchased against vendor type.

We identified patterns of behavior that undermine the traceability regulations ADIO are required to adhere to. We found that vendors removed eggs from ADIO bags to sell fewer eggs than the ADIO units of 10 or 20 eggs. When we compared the number of eggs sold in each bag, against the number of eggs that should legally be in that bag, we found vendors split bags and reduced the contents by half, regardless of whether the regulated unit pack size was 10 or 20 eggs. There were not enough examples of misused bags (10 eggs = 9, 20 eggs = 8) to run statistical analysis; however, this pattern is of interest as it suggests that the vendors struggled to sell bags of 10, and this continued to be a problem when ADIO increased the bag size to 20 eggs. To our knowledge, it is not possible to acquire empty ADIO bags, and therefore, it is assumed the surplus eggs were sold in blank bags. Finally, we found that vendors were selling eggs at significantly higher prices than the ADIO price of €150 per egg ($t[40] = 247.9$, $p < .001$), up to €500 per egg (€381.4 ± 168.9 mean ± SD).

3.2 | Species identification

3.2.1 | DNA

During our surveys, we purchased 472 eggs, of which 356 were shelled eggs (fresh or cooked) and 116 were in *sangrita*. In the event eggs were illegally sourced, it is possible eggs bagged together would be from the same nest. Therefore, we did not run DNA analysis on every egg and limited this to a maximum of three eggs per bag. Consequently, we ran the DNA analysis on 279 eggs. Of those, 106 samples had a positive PCR result, meaning there was sufficient genetic material for Alu I digestion. The enzyme Alu I was successful in digesting 92 out of 106 PCR products. Of these, 91 (98.9%) amplified, resulting in cleavage amplification polymorphisms (CAPs) at fragment sizes of approximately 60, 300, and 500 bp, indicating that they belong to the species olive ridley (*L. olivacea*). Only one (1.08%) of the sampled eggs was from a different species—an Atlantic green (*C. mydas*), with fragment sizes of approximately 180, 220, and 460 bp.

We found a significant association between the method by which eggs were prepared and whether DNA amplified (amplified: cooked $n = 19$, *sangrita* $n = 22$, and fresh $n = 9$; did not amplify: cooked $n = 20$, *sangrita* $n = 27$, and fresh $n = 34$, $\chi^2[2] = 8.24$, $p < .05$) reflecting the fact that raw eggs were the least successful at amplification. We attribute this to adopting the methodology of Moore et al. (2003) that specifically used cooked materials in their genetic analysis.

3.3 | Other methods of species identification

Cooking eggs did not significantly alter the size of eggs ($U[731]$, $p > .05$, $n = 38$ fresh: 38.27 mm ± 1.72 [mean ± SD]; cooked: 38.27 mm ± 1.8 [mean ± SD]). The diameters of the olive ridley eggs, confirmed using genetic analysis, ranged from 35.0 to 42.7 mm, 38.9 ± 1.77 [mean ± SD] $n = 91$. Based on the diameters of all shelled eggs, 285 eggs which were not identified using genetic analysis, fell within the size range for olive ridley turtle eggs. Including both the eggs confirmed with genetic analysis, and those from diameter measurements, suggests 80.09% of our eggs were from olive ridley turtles. The confirmed green turtle egg (44.0 mm) was purchased with another egg (43.5 mm), which we also believe was from a green turtle. We also suspect that a separate batch of eggs were green turtle (diameters 44.9, 46.6, and 47.0 mm). Any egg over 50.0 mm is unmistakably

TABLE 2 Frequency of species identified by genetic analysis and nongenetic methods.

Species	Number of shelled eggs identified through genetic analysis	Number of egg yolks in *sangrita* identified through genetic analysis	Species identified based on size of egg diameter (mm)	Species identified by other means (geography, phenology, etc.)	Total
Olive ridley	57	35	285	1[a]	**378**
Green	1	0	4	0	**5**
Leatherback	0	0	6	0	**6**
Hawksbill	0	0	0	0	**0**
Inconclusive	0	81	2	0	**83**
Total	**58**	**116**	**297**	**1**	**472**

Note: Each of 472 eggs allocated once ($n = 118$ shelled cooked, 238 shelled fresh, 116 yolks in *sangrita*).
[a]Egg diameter within the size range for hawksbill but purchased outside nesting season for this species, therefore, more likely to be unusually small olive ridley egg.

leatherback, as its egg sizes do not overlap with other species in our study. Based on their sizes (50.2, 52.1, 52.4, 52.8, 52.8, and 53.8 mm), we believe six specimens to be leatherback eggs. These eggs were purchased together as a single transaction. Finally, we identified two eggs from a mobile vendor in Puerto Limón during peak green nesting season with diameters 43.4 mm and 42.0 mm. These eggs remain inconclusive as their diameters are borderline with a large olive ridley and small green turtles, but they were purchased in Puerto Limón during peak green nesting season (Table 2).

3.4 | Market observations

The following observations were made during egg purchases. A mobile vendor in Siquirres made a noteworthy comment during the transaction where we purchased olive ridley eggs from a cool box. The vendor volunteered, “I only sell larger eggs after dark.” The implication was that the larger eggs were from green or leatherback turtles. Visiting bars near Cariari, two vendors, who did not have eggs in stock at the time said they source their eggs from Tortuguero and Barra del Colorado (north of Tortuguero) but could get Ostional eggs, if required. On two occasions, Central Valley stallholders told us they need to open the ADIO bags, as customers often do not want to purchase a full pack of eggs. “I sometimes sell them singly because people ask for just one or two.” We also identified situations where vendors appeared keen to demonstrate they were operating within the law. On three occasions, mobile vendors selling eggs from a cool box (two in Guapiles and one in Siquirres) voluntarily showed the research assistant their permits. On a separate occasion, in Limón, a mobile vendor selling cooked egg from a cool box had an open ADIO bag inside the box, clearly visible when he opened the cool box. We interpret this as an indication that he wanted to demonstrate he had legally acquired his eggs.

4 | DISCUSSION

We identified two types of illegal activities taking place in the open markets of Costa Rica. First, the trade of eggs of protected turtle species, such as leatherback and green turtles (2.29% of vendor visits where we purchased eggs); and second, retailers failing to adhere to the traceability rules (96.9% of visits). We found evidence that eggs from two illegal species were for sale in Limón province, from three separate vendors. Despite undertaking surveys during the peak nesting period of Caribbean hawksbill turtles (April–July), we did not identify this species in the trade. Hawksbill turtle eggs are unlikely to appear in the open market due to their rarity and lack of a financial premium for the eggs of this species. The illegal take of these eggs is known to take place on the Caribbean coast (Pheasey, Glen, et al., 2021); however, a localized underground black market is a more likely sales outlet, rather than one that carries greater risk by transporting them inland from the Caribbean coast. The rarity of hawksbill eggs, in combination with our sampling, may account for them not appearing in our data. However, we found no evidence that Ostional specifically is being used as a cover to sell illegal species' eggs.

Almost a third (32.6%) of the eggs tested using DNA analysis allowed for a positive species identification. We were then able to extrapolate the identification of the remaining shelled eggs based on their measurements. Despite this relatively small sample size, we are confident that it is sufficient to demonstrate that egg size is an accurate measure of species identification than could be applied in the markets. The exception to this are eggs sold in *sangrita*. However, there is a practical reason why we do not fear this to be a laundering method for other species. The objective for consuming eggs in *sangrita* is to be able to swallow them whole as a "shot," much like liquor. The yolks of green and leatherback eggs are too big to comfortably enable this, which only leaves hawksbills as the vulnerable species. We established earlier in this discussion why it is unlikely hawksbill eggs are in the open market. We avoided sampling eggs from heat-sealed ADIO bags (unless they contained visibly large eggs [$n = 0$]), as we have no reason to believe laundering of illegal eggs would take place at the point of harvest. ADIO's capacity to harvest, package, and transport eggs to San José is at its limit, and there is no incentive to add non-*arribada* eggs. Nesting events of other species are infrequent in Ostional, and those nests are moved to a hatchery by volunteer teams. Therefore, any laundering would take place through using open bags or non-ADIO bags. In addition, given that we checked ADIO bags on display for visibly larger eggs, finding nothing untoward, we suggest it is highly unlikely vendors are refilling and resealing opened ADIO bags to launder other species' eggs.

The management plan for ADIO states that eggs must be sold in heat-sealed bags embossed with the ADIO logo. The only exception to this is under Article 11 of Executive Decree #28203 that allows retailers to sell ADIO eggs from an open packet if they are for consumption on the premises. We only identified one occasion (0.76% of vendor visits) when a vendor adhered to this rule and refused to sell their eggs on the grounds they were not for consumption on site; on every other occasion, we were able to purchase eggs and take them off the premises. We found three ways vendors were flouting the traceability rules: (1) selling fresh eggs outside ADIO packaging (32.8%); (2) cooked eggs sold for consumption off the premises (29.8%); and (3) eggs in *sangrita* also for consumption off the premises (37.4%). Mobile vendors also commonly sold eggs in *sangrita*, in small disposable pots. Without a fixed point of sale, these vendors cannot adhere to Article 11. We therefore found that 96.9% of the trade was conducted in a manner that breached the traceability regulations, rather than trading illegal species' eggs. In addition, although our findings show that most eggs available in the open market are from olive ridley turtles, we also found vendors sold eggs of olive ridley turtles at higher prices than ADIO, whether this be fresh eggs or prepared. This implies that although ADIO strives to adhere to the traceability rules, these rules are only successful until the eggs reach the retailer. Because of the apparent consumer demand for low quantities of fresh eggs or eggs that have been prepared, the system breaks down between the retailer and consumer, as the retailer struggles to sell eggs in the required quantities.

It is important to distinguish between eggs collected from a fully protected species (i.e., green, hawksbill or leatherback turtles) and illegally collected olive ridley eggs. Currently, it is not possible to trace an olive ridley turtle egg back to the beach of origin, meaning uncertified eggs cannot be traced to Ostional. Mitigation of wildlife laundering to improve the traceability of Ostional eggs is problematic. In the case of the trade in green pythons (*Morelia viridis*) from Indonesia, Lyons and Natusch (2011) recommend the sale package of farmed live pythons to include the egg from which it hatched. This would provide a genetic trace that the python was farm sourced and not harvested from the wild. Requiring bars to sell eggs cracked into *sangrita* with the eggshell would be the equivalent to this. This type of approach may assist in the confirmation that an egg in *sangrita* is from an olive ridley turtle but does not confirm the egg originated in Ostional. Based on eggs that have been identified using DNA analysis, we have shown that olive ridley eggs range in size from 35.0 mm to 42.7 mm in Costa Rica. This varies slightly from the global averages reported by the IUCN (37–42 mm) (Pritchard & Mortimer, 1999) and offers enhanced law enforcement opportunities; market eggs outside of these size dimensions are questionable, and the species identification can be verified through genetic analysis. Another suggestion has been to use dye to mark Ostional eggs, much in the same way supermarkets label chicken eggs (Hope, 2002); however, this is unlikely to be feasible. This is because the Ostional community does not have the capacity to mark the volume of eggs (in 2018, over 3 million eggs were packaged and shipped from Ostional (Lobo-Glez, 2019)) in a way that would be appropriate for a wet soft turtle egg, bagged with sand; once smudged, or the egg boiled, the mark may be unrecognizable.

When marketing a wildlife commodity with the aim of reducing wild or unsustainable offtake, the success of such a system is dependent on the availability of an acceptable alternative, at a lower cost to the consumer (Bulte & Damania, 2005). One of the key requirements of the Ostional harvest is that eggs retail at a price low enough to undermine the illegal trade (Valverde, 1999). However, we have found that the current traceability rules are misaligned with consumer demand. Paying less per transaction appears to be more important to the consumer, than the value for money they get from the purchase of a greater quantity of eggs. To realign this, we recommend making the following adjustments to the system: (1) sell eggs in smaller quantities, ideally five or six eggs and undertake a feasibility study into 'boil in the bag' options. Consumer demand is currently driving vendors to open the small Ostional bags to cook the eggs. This could be circumvented by removing the need to open the bags by providing eggs inside packaging suitable for boiling (cooked eggs on average retail at three eggs for ₡1000 ($2)). (2) Package the fresh eggs in smaller bags so there is less excess plastic to retie the opened bags. (3) Establish consumer willingness-to-pay for a smaller quantity of eggs, through a market research survey. Based on our data, we predict customers would pay ₡1000 for five fresh eggs. This may prove to be adequate compensation for the additional labor required by the Ostional community to package eggs in smaller quantities. In 2002, Hope suggested "Labelling the eggs individually or in smaller unit bags that correspond to consumer buying preferences." This was suggested to be an appropriate response to reducing the confusion that consumers face regarding the authenticity of legal eggs (Arauz Almengor et al., 2001). Since then, ADIO moved from sacks of 200 eggs to the smaller bags of 10 then 20 eggs. Our evaluation suggests that although this is a positive direction, a further step is required to ensure the optimum marketing strategy is adopted. We also urge caution when reconsidering packaging options. The damaging environmental impact of plastics, particularly in the oceans, is becoming increasingly apparent, and sea turtles are at the forefront of the issue (Ivar do Sul et al., 2011; Robinson & Figgener, 2015). We suggest that rather than viewing these as separate challenges, they are considered in unison, to ensure a more sustainable trade in terms of both market forces and waste reduction. Furthermore, Hope (2002) suggested pricing trials to compare demand between seasons and regions could enhance marketing opportunities. Hope (2002) suggested wholesaler auctions with a "price floor" would assist in establishing more appropriate pricing, but to our knowledge, this is yet to be trialed.

Whether the Ostional project is stimulating demand for sea turtle eggs, or confusing consumers into believing that all turtle eggs are legal, is beyond the scope of this study. In addition to finding no evidence of laundering of illegal species' eggs under the Ostional scheme, we instead found incidences of the *open* sale of illegal species' eggs. However, this was relatively uncommon and limited to towns in Limón province in the Caribbean. Other studies have established the trade in sea turtle eggs in Costa Rica is supply driven (Pheasey et al., 2023; Pheasey, Glen et al., 2021). The majority of Ostional eggs are sold in towns in Limón (28%) and San José (25%) (Lobo-Glez, 2013–2018; Lobo-Glez, 2019). Accessing nesting beaches from these locations is both time consuming and expensive, as well as illegal. This suggested that although there is high demand for turtle eggs, the majority of trade takes place because traders make available a hard-to-access product. Illegal trade in the Caribbean occurs in short trade chains from beach to end consumer via door-to-door local sales (Mejías-Balsalobre et al., 2021; Pheasey et al., 2023). All legally harvested eggs are sold, suggesting there is a significant demand for sea turtle eggs, which is currently being met in urban areas by the legal trade satisfying the market. Removing the legal trade would therefore allow the potential for illegal eggs to become more profitable. This is currently held at bay by the physical barriers to illegal trade and the relatively stable fixed price of legal eggs (Pheasey, 2020). Furthermore, livelihoods of mobile vendors, who predominantly sell cooked eggs, are dependent on egg sales. Although this group is the least accountable for the traceability of their eggs, we advise caution in reviewing their sale strategy. Mobile vendors are meeting a demand from what currently appears to be a sustainable source. Should this supply diminish it is possible illegal egg sales may increase to fill this gap.

When attempting to address non-compliance or rule breaking in conservation, law enforcement is an obvious strategy. However, this is often hampered by insufficient resources. Despite its stringent wildlife protection laws, Costa Rica is not exempt from these limitations (Pheasey et al., 2020; Pheasey, Matechou, et al., 2021). However, it has also been found that in cases where demand for a product is high, as we identified, law enforcement may not be the best strategy. Governance has been found to be inadequate in challenging consumer demand (Challender & MacMillian, 2014). Furthermore, criminalizing those who are simply attempting to undertake basic livelihood tasks without providing opportunities to input into the conservation process raises serious ethical considerations (Solomon et al., 2015). This can lead to hostilities and result in petty criminal behavior as a form of protest, thereby undermining conservation action (Hinsley et al., 2017). Our article has contributed to a part of this understanding using the case study of eggs from Ostional. We have identified misdemeanors in the application of the traceability regulations, not only in the non-compliance of traders but also how this relates to consumer demand. Importantly, we identified the importance of substitutes and the dangers of removing a legally sourced product from the market. Our work is directly relevant to conservation practitioners working toward the improvement and sustainability of the Ostional harvest within Costa Rica, namely INCOPESCA and MINAE. Furthermore, legal harvests of sea turtle eggs have taken place in El Salvador, Guatemala, Nicaragua, and Panama, with varying degrees of success (Evans & Vargas, 1996; Handy et al., 2006; Massey & McCord, 2017). Our work enhances the understanding of the Inter-American Convention for the Protection and

Conservation of Sea Turtles that uses the Ostional model to inform policy for these projects. Finally, La Escobilla, Mexico is a nesting beach of interest to proponents of sustainable harvest and our findings offer a timely contribution to this debate.

AUTHOR CONTRIBUTIONS

HP and DLR designed the study. HP gathered the data. AAF conducted the laboratory analysis and HP conducted the statistical analyses. FJA provided lab resources. HP, DLR, and RAG drafted the manuscript. All authors contributed to the text. All authors agree to be held accountable for the content therein and approve the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Genetic data and data that does not identify participants will be available from the Kent Academic Repository on acceptance of manuscript.

ETHICS STATEMENT

The School of Anthropology and Conservation's Research Ethics Advisory Group (University of Kent) approved this research (Ref. No. 0381617c).

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