From pets to plates: network analysis of trafficking in tortoises and freshwater turtles representing different types of demand

Ramya Roopa Sengottuvel, Aristo Mendis, Nazneen Sultan
Shivira Shukla, Anirban Chaudhuri and Uttara Mendiratta

Abstract Despite being protected under the law, illegal trade in tortoises and freshwater turtles is common in India, with different species being trafficked for different markets. Indian species of tortoises and hard-shell turtles are predominantly trafficked for the pet trade and soft-shell turtles for the meat trade. Given their distinct markets, the operation of trade may vary between these different groups of tortoises and freshwater turtles, thereby necessitating different types of interventions. However, a systematic examination of illegal trade in tortoises and freshwater turtles that takes into account the differences between these markets is currently lacking. Here we compare the supply networks of tortoises/hard-shell turtles (in demand for pet trade) vs soft-shell turtles (meat trade), using information from 78 and 64 seizures, respectively, that were reported in the media during 2013–2019. We used social network analysis to compare the two networks and the role of individual nodes (defined as locations at the district or city scale) within these networks. We found that the tortoise/hard-shell turtle network had a larger geographical scale, with more international trafficking links, than the soft-shell turtle network. We recorded convoluted smuggling routes in tortoise/hard-shell turtle trafficking, whereas soft-shell turtle trafficking was uni-directional from source to destination. Within both networks, we found that a few nodes played disproportionately important roles as key exporting, importing or transit nodes. Our study provides insights into the similarities and differences in the illegal supply networks of different groups of tortoises and freshwater turtles, in demand for different markets. We highlight the need for intervention strategies tailored to address the illegal trade in each of these groups.

Keywords Illegal trade, India, meat trade, pet trade, seizure, social network analysis, tortoise, freshwater turtle

Ramya Roopa Sengottuvel* (Corresponding author, orcid.org/0000-0002-6532-6090, ramyu.wildlife94@gmail.com), Aristo Mendis (orcid.org/0000-0002-5350-4400), Nazneen Sultan (orcid.org/0000-0002-8970-0788), Shivira Shukla (orcid.org/0000-0002-9889-7885), Anirban Chaudhuri and Uttara Mendiratta (orcid.org/0000-0003-1267-2886) Wildlife Conservation Society – India, Bengaluru, India

*Currently at: Wildlife Conservation Trust, Mumbai, India

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Introduction

Illegal wildlife trade is a major threat to biodiversity, with far-reaching consequences for society, security (Wyatt, 2013) and public health (Greatorex et al., 2016; Smith et al., 2017). Thousands of species, including many that are threatened, are traded illegally to meet consumer demand for trophies, food, clothing, decorative items, pets and traditional medicine (Rosen & Smith, 2010). In the illegal trade of live wildlife, reptiles, specifically testudines (tortoises and turtles), are amongst the most trafficked (Bush et al., 2014; Auliya et al., 2016). Recent assessments indicate that exploitation for subsistence and commercial purposes represents a major threat for this group (Stanford et al., 2020).

Tortoises and turtles are of significant conservation concern because of several life history traits (late sexual maturity, long reproductive lifespans, low reproductive output and extreme longevity) that render them vulnerable to overexploitation and extinction (Congdon et al., 1994; Sung et al., 2013; Lovich et al., 2018). This problem is particularly acute in Asia, where large-scale exploitation for food, traditional medicine and the pet trade has contributed to severe declines in wild populations, a phenomenon that has been termed the Asian turtle crisis (Cheung & Dudgeon, 2006). With evidence of both illegal domestic and international trade in tortoises and freshwater turtles, India plays an important role in this ongoing crisis (Cheung & Dudgeon, 2006; Mendiratta et al., 2017).

At least half of the 30 tortoise and freshwater turtle species of India have been documented in illegal trade (Mendiratta et al., 2017), including one species categorized as Critically Endangered on the IUCN Red List, seven Endangered and four Vulnerable species. All but four of these species are protected under the Wild Life (Protection) Act, 1972 of India, which prohibits hunting and trade in these species. Nevertheless, the scale and volume of illegal trade is immense, with different groups of tortoises and freshwater turtles being trafficked for different markets. Tortoises (family Testudinidae) and hard-shell turtles (family Geoemydidae) harvested in India are trafficked largely for commercial pet markets in Southeast Asia and China (Chng, 2014; D'Cruze et al., 2015; Mendiratta et al., 2017; Leupen, 2019), whereas soft-shell turtles (family Trionychidae) are primarily hunted and traded for their meat (Krishnakumar et al., 2009; Bhupathy et al., 2014; Mendiratta et al., 2017). Live soft-shell turtles are collected from across the Ganges, Indus and Mahanadi Rivers to meet the domestic demand for meat, largely in eastern India (Choudhury & Bhupathy, 1993) and internationally along the India–Bangladesh border (Mendiratta et al., 2017). Although soft-shell turtles are also hunted for their calipee (a fatty, gelatinous substance present over the lower shell) and fibrocartilage (the leathery outer margin of the shell; Das & Singh, 2009) for their use in traditional medicines and soups, the extent and frequency of such trade from India remain unknown.

Previous studies have contributed to the understanding of illegal trade in tortoises and freshwater turtles in India through market surveys (Moll, 1990; Choudhury & Bhupathy, 1993), field surveys (D'Cruze et al., 2015), undercover investigations (Stoner & Shepherd, 2020) and analyses of media-reported seizures (Mendiratta et al., 2017). These studies have either examined illegal trade in tortoises and freshwater turtles as a whole, or focused on specific species such as Indian star tortoises *Geochelone elegans* (D'Cruze et al., 2015) and spotted pond turtles *Geoclemys hamiltonii* (Chng, 2014; Leupen, 2019). However, an in-depth empirical examination of the illegal supply chain of tortoises and freshwater turtles by type of demand or market is currently lacking. Given their distinct markets, we expect that the ways in which illegal trade operates for the different groups of tortoises and freshwater turtles will vary, and understanding such variation could aid in tailoring appropriate interventions.

Social network analysis has emerged as a useful tool for understanding crime, through the study of relationships or flow of goods between actors (defined as individuals, groups, organizations or locations; Clifton & Rastogi, 2016). It has been used to determine the role of specific locations in drug supply networks (Giommoni et al., 2017) and to uncover the structures of terrorist (Gregori & Merlone, 2020) and human trafficking networks (Wang et al., 2018). In recent years, this approach has been applied to illegal wildlife trade, to identify key locations in the global trafficking of rhinoceroses, elephants and tigers (Patel et al., 2015), the trafficking of pangolins in China (Cheng et al., 2017), wild birds in Indonesia (Indraswari et al., 2020) and ivory (Huang et al., 2020), and to identify key offenders in rhinoceros poaching networks (Haas & Ferreira, 2015).

Here we employ this tool to study and compare the location-based illegal supply networks of tortoises/hard-shell turtles and soft-shell turtles, which are in demand for the pet and meat trade, respectively. We constructed the networks to represent trafficking flows between nodes (defined as locations at the district or city scale) for tortoises/hard-shell turtles and soft-shell turtles, using 78 and 64 seizures reported in the media during 2013–2019, respectively. We used metrics of social network analysis to compare the two networks and the roles of individual nodes within these networks. We identified key locations along the trafficking routes, where targeted enforcement actions could have disproportionate impacts in disrupting this trade. In doing so, our goal was to highlight similarities and differences in the operation of illegal trade involving tortoises and freshwater turtles that are in demand for different illicit markets, to inform appropriate interventions for each of these groups.

Methods

Data collection

We conducted a systematic online search for media-reported seizures of tortoises and freshwater turtles originating from India for the period 1 January 2013–31 December 2019 using the Google search engine (Google, 2019). We conducted year-wise searches using the Advanced Search tool with the following keywords: 'seize turtle', 'seizure turtle', 'poach turtle', 'seize tortoise', 'seizure tortoise', 'poach tortoise'. We used the same keyword combinations in general Google search and Google News search. We carried out this data collection during May 2019–January 2020.

We searched through all reports, bulletins and news articles hosted within the following websites for seizures of tortoises and freshwater turtles between 2013 and 2019: Robin des Bois (2022), TRAFFIC Post (TRAFFIC India, 2017), TRAFFIC Bulletin (TRAFFIC, 2020) and South Asia Wildlife Enforcement Network (2015). Collected seizure reports were in English and seven regional languages of India. From each seizure report, we extracted the following information: date of incident, species involved, product type (live, meat, shells, bones or calipee), product quantity (units/weight) and transportation involved. We documented the location of the seizure, source (i.e. reported location of harvest of the seized tortoises and freshwater turtles), last transit location(s) prior to detection and actual or intended destination location(s) of the consignment, where these were stated. We recorded location information at the city/village, district, state and country scale. For those incidents for which source, last transit or destination location(s) were not specified in the seizure report, we searched for additional media reports on the same incident to fill these information gaps.

In addition, for all recorded seizures we attempted to confirm species identity through cross-verification with data from an earlier study (Mendiratta et al., 2017) and expert help. In this step, we first verified that images published with each seizure report were actually from the reported seizure and not stock images, using online reverse image search tools such as Google Images (Google, 2016) and TinEye (Idée, 2008; as per methods described by Mendiratta et al., 2017). When images were unavailable, we searched for additional media reports or YouTube (Google, 2017) videos of the specific seizure incident. We then used expert help to confirm the species identity for those seizures with original images or videos. When we were unable to confirm species identity, we noted this as 'Unspecified'. Of the collected seizure records, we retained only those incidents in which the seizure or poaching occurred in India, or consignments of tortoises and freshwater turtles seized elsewhere that had originated from India and where species of tortoises and freshwater turtles native to India were involved. Lastly, we grouped all species into two categories for further analysis: tortoise/hard-shell turtle or soft-shell turtle.

Analysis

We built our network dataset for tortoises/hard-shell turtles and soft-shell turtles using seizures that contained information on either source, last transit or destination location(s). We parsed seizure reports with multiple such trafficking connections into separate entries (Patel et al., 2015). For example, we parsed a consignment of 50 Indian star tortoises transported from Chennai (last transit location) to Bengaluru (seizure location) to Kuala Lumpur (intended destination location) into two separate entries of 50 tortoises/hard-shell turtles transported from Chennai to Bengaluru and from Bengaluru to Kuala Lumpur.

We constructed the networks such that nodes represented districts (for locations within India; e.g. Chennai district) or cities (for locations outside India; e.g. Bangkok), and each link represented a directed trafficking connection between any two nodes (Figs 1 & 2). We categorized those locations that were mentioned in the seizure report only at the scale of state (within India) and country (outside India) as 'Unspecified – (state name)' or 'Unspecified – (country name)'. For example, we categorized a consignment moving from Bengaluru district to an unspecified district in West Bengal as moving from node 'Bengaluru' to node 'Unspecified – West Bengal'. Similarly, we categorized a consignment moving from North 24 Parganas district to an unspecified city in Bangladesh as moving from node 'North 24 Parganas' to node 'Unspecified – Bangladesh'. For our analysis, we combined the districts of Bengaluru (Bengaluru Urban and Bengaluru Rural) and Delhi (New Delhi, Central Delhi, East Delhi, North Delhi, etc.) into the single nodes of 'Bengaluru' and 'Delhi', respectively.

We used social network analysis metrics to compare the networks at two levels: the node and the entire network. Firstly, we calculated the following node-level centrality measures: degree (in-degree, out-degree and total degree), strength (in-strength and out-strength) and betweenness. Degree (or total degree) centrality represents the number of links directly associated with a node. In-degree and out-degree represent the number of incoming trafficking links arriving at and outgoing links exiting from a node, respectively (Freeman, 1978). In-strength and out-strength represent the total volume (i.e. number of individuals of tortoises/hard-shell turtles or soft-shell turtles) arriving at and exiting a node, respectively (Barrat et al., 2004; Patel et al., 2015; Cheng et al., 2017). Betweenness centrality measures the number of times a node was present on the shortest directed path between other pairs of nodes in the network (Freeman, 1978). Nodes with high betweenness have greater influence or control over the trade flow within the network, thus acting as key intermediaries (Hughes et al., 2017).

Additionally, we identified optimal sets of nodes, known as key players, that when removed from the network would result in maximal lengthening of the distance between pairs of the remaining nodes, essentially disconnecting some pairs (Borgatti, 2006; Patel et al., 2015; Cheng et al., 2017). To identify this set, we used a distance-weighted fragmentation index, which is based on the sum of reciprocal distance between remaining nodes in the network, when key players are removed (Borgatti, 2006). Values of this index range from 0 (completely connected network) to 1 (networks composed entirely of isolated nodes). For this measure, we considered network data as non-directional (i.e. without considering the direction of flow) and unweighted (i.e. without considering the volume associated with a trafficking link).

At the network level, we calculated in-degree, out-degree and betweenness centralization using the node-level in-degree, out-degree and betweenness scores (see Supplementary Table 1 for details). Centralization measures the variation in the centrality score of individual nodes in the network relative to the highest centrality score observed within the network (Supplementary Table 1; Freeman, 1978). Higher centralization scores imply that only a few nodes are central in the network (Gregori & Merlone, 2020).

We also calculated other metrics such as mean degree (mean of total degree in the whole network), link density (ratio of observed number of trafficking links to the number of possible trafficking links; Wasserman & Faust, 1994) and reciprocity (proportion of mutual or bi-directional trafficking links between nodes in a directed network). We conducted the network analysis using the package *igraph* (Csardi et al., 2006) in *R 4.0.2* (R Core Team, 2021). We identified key players using the programme *KeyPlayer 1.44* (Borgatti, 2003).

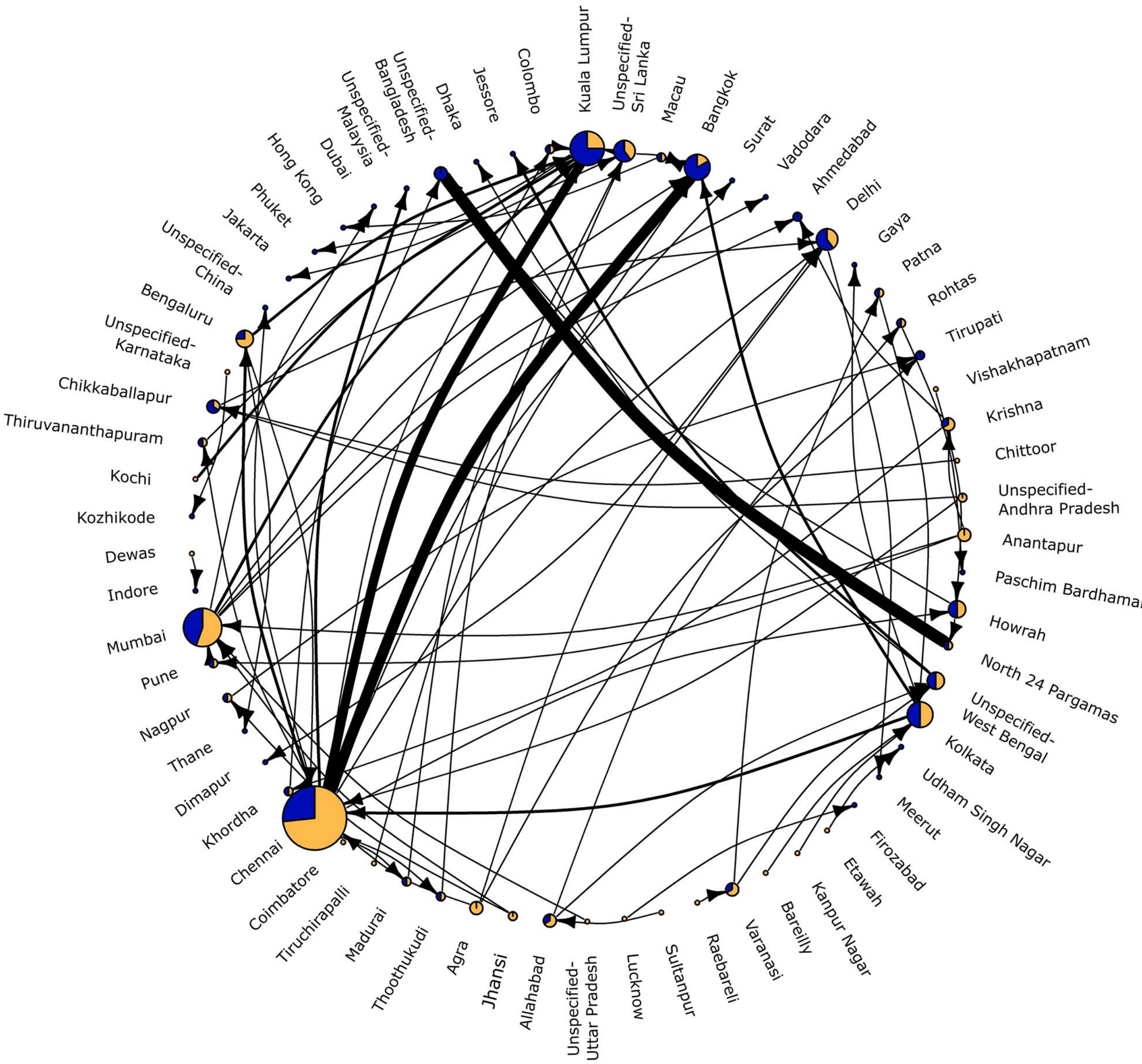

FIG. 1 Network graph of media-reported trafficking links involving Indian tortoises/hard-shell turtles during 2013–2019. Each node represents a district (for locations within India) or a city (for locations outside India). Node size is proportional to its total degree (sum of outgoing and incoming trafficking links), wherein the dark (blue) and light (orange) portions represent the numbers of incoming and outgoing trafficking links, respectively. The thickness of the lines (representing trafficking links) is proportional to the number of incidents in which that trafficking link was reported. (Readers of the printed journal are referred to the online article for a colour version of this figure.)

Results

We recorded 268 incidents involving poaching or illegal trade of tortoises and freshwater turtles within India or originating from India during 2013–2019. Live or dead tortoises/hard-shell turtles and soft-shell turtles were seized in at least 118 and 103 incidents, comprising > 21,000 and 53,000 individuals, respectively. Of 118 seizures containing live tortoises/hard-shell turtles, 74 were made in transit (29 in airports, 24 on roads and 21 in railway stations). For live soft-shell turtles, 61 seizures were made in transit (36 on roads, 24 in railway stations and one in an airport). Information on consignment source, last transit or destination location(s) was available for 78 and 64 seizures for tortoises/hard-shell turtles and soft-shell turtles, respectively. We used these seizures for the construction of the location-based supply networks (Figs 1–4).

Tortoise/hard-shell turtle trafficking network

The tortoise/hard-shell turtle trafficking network comprised 65 nodes (in eight countries) and 75 unique trafficking links, corresponding to 1.8% of all possible links (link density =

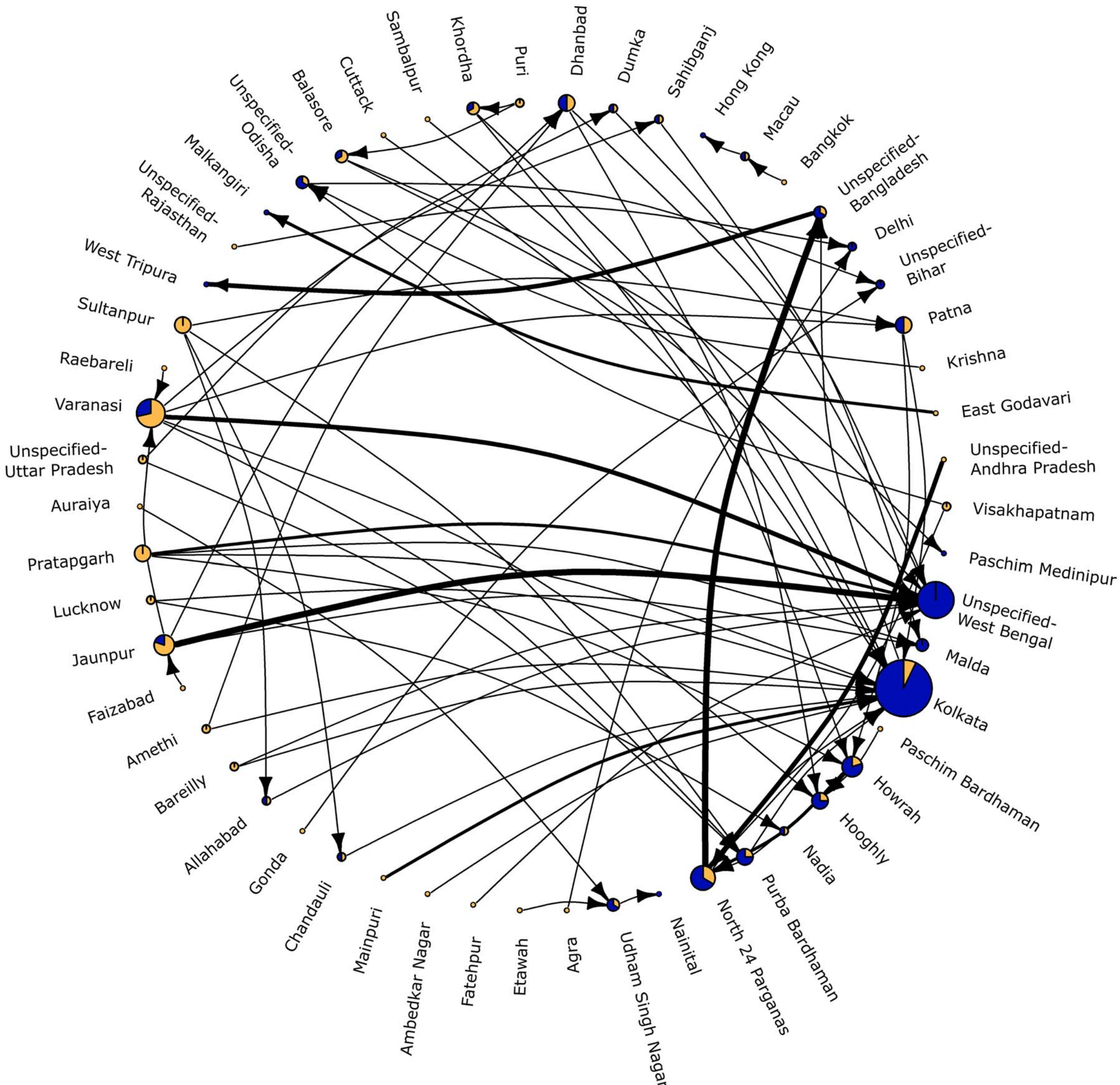

FIG. 2 Network graph of media-reported trafficking links involving Indian soft-shell turtles during 2013–2019. Each node represents a district (for locations within India) or a city (for locations outside India). Node size is proportional to its total degree (sum of outgoing and incoming trafficking links), wherein the dark (blue) and light (orange) portions represent the numbers of incoming and outgoing trafficking links, respectively. The thickness of the lines (representing trafficking links) is proportional to the number of incidents in which that trafficking link was reported. (Readers of the printed journal are referred to the online article for a colour version of this figure.)

0.018; Table 1). On average, each node had trafficking links with two other nodes in the network (mean degree = 2.31). Of the 75 unique trafficking links, 27 were international; the most documented links were North 24 Paragnas (in eastern India) to unspecified district(s) in Bangladesh, followed by Chennai (in southern India) to Bangkok (Thailand) and Chennai to Kuala Lumpur (Malaysia; Fig. 1).

Network-level centralization scores indicated an uneven distribution of incoming and outgoing trafficking links between the nodes (Table 1). The network was more centralized in terms of out-degree (out-degree centralization = 0.156) than in-degree (in-degree centralization = 0.077). This indicated that a small number of nodes supplied (within India) or exported tortoises/hard-shell turtles to a large number of nodes within the network, whereas the majority of nodes had one or few nodes to supply (within India) or export to. In addition, two-way trafficking of tortoises/hard-shell turtles was documented between a few nodes in the network (reciprocity = 0.027). Low betweenness centralization (0.038) indicated that the betweenness centrality scores of the nodes were evenly distributed.

In terms of node-level centrality measures, a few nodes emerged as key importing, exporting or transit locations (Tables 2 & 3). Chennai, a state capital in southern India, was identified as the most central node in the tortoise/hard-shell turtle trafficking network. It was the highest-ranked node in terms of number of outgoing trafficking links

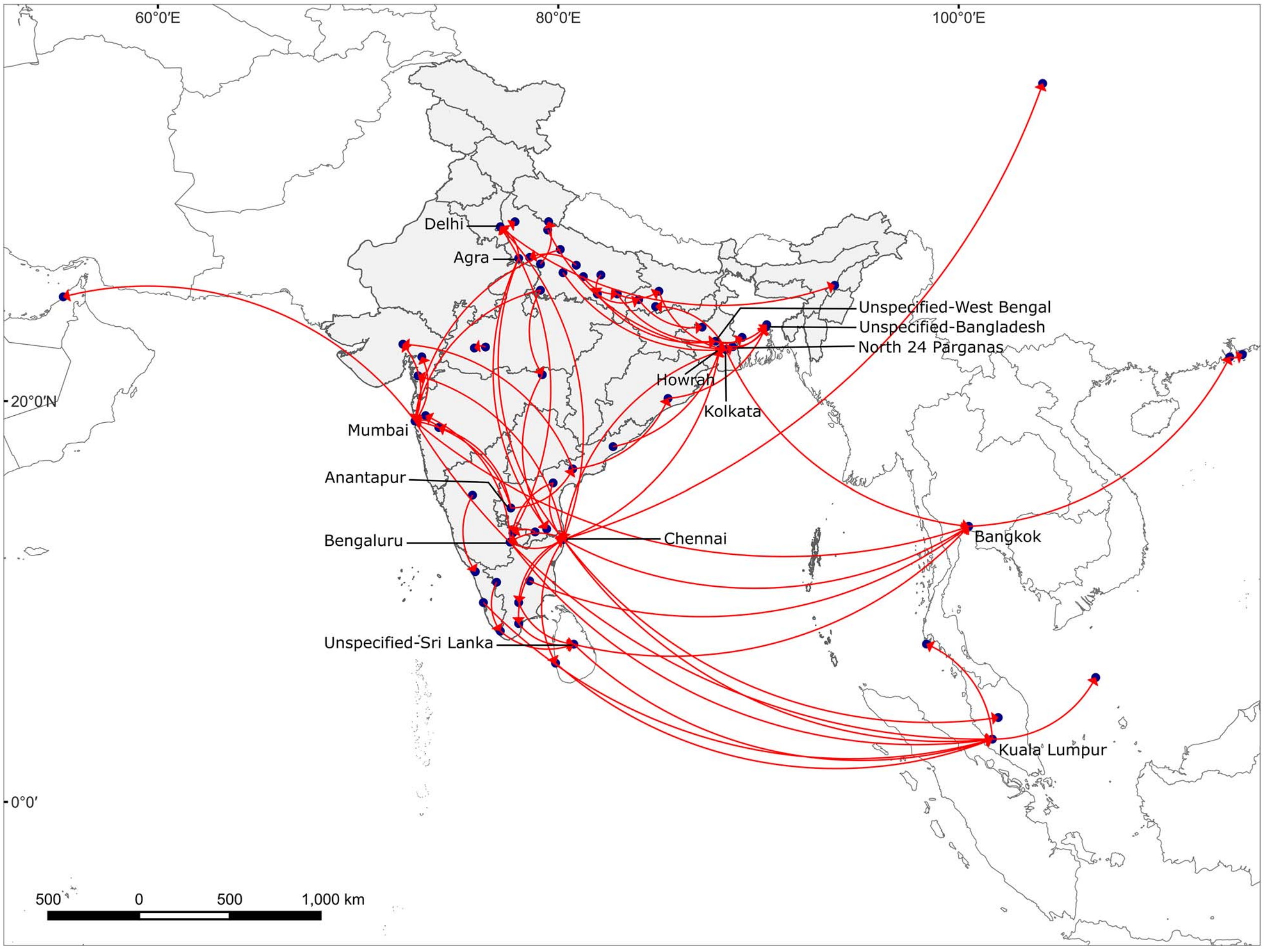

FIG. 3 Map of media-reported trafficking links involving Indian tortoises/hard-shell turtles during 2013–2019. Points represent nodes (district-scale for locations within India or city-scale for locations outside India) and arrows depict the directionality of trafficking of tortoises/hard-shell turtles between nodes. Only key nodes are labelled. Refer to Supplementary Fig. 1 for a map with a full list of labelled nodes.

(out-degree) and in terms of outgoing volume of tortoises/hard-shell turtles (out-strength). Three other state capitals (Mumbai, Kolkata and Bengaluru) and two non-capital nodes (Anantapur and Agra) ranked highly in terms of number of outgoing links. North 24 Parganas and Howrah, districts located close to the India–Bangladesh border, also ranked highly in terms of out-strength (Table 2).

Key importing nodes were largely located outside India for tortoises/hard-shell turtles. Kuala Lumpur (Malaysia), Bangkok (Thailand) and unspecified district(s) in Bangladesh were identified as the most important importing nodes because of the large number of incoming trafficking links (in-degree) and high volume (in-strength; Table 2). Within India, Chennai and Mumbai had the highest numbers of incoming trafficking links in this network, indicating their role as transit or collection points for further export abroad. Chennai and Kolkata also ranked highest in terms of betweenness centrality (Table 2).

Fragmentation indices further support the asymmetric roles played by specific nodes in the network. Removal or isolation of Chennai alone through targeted interventions could fragment nearly 83% of the network (Table 3). A few other key nodes that did not rank highly with other network metrics had a high fragmentation index: Unspecified – Sri Lanka, Unspecified – West Bengal and Delhi.

Soft-shell turtle trafficking network

The soft-shell turtle trafficking network comprised 54 nodes (in four countries) and 69 unique trafficking links, corresponding to 2.4% of all possible links (link density = 0.024; Table 1). On average, each node had trafficking links with two to three other nodes in the network (mean degree = 2.56). Trafficking in soft-shell turtles was predominantly domestic in nature, with only five trafficking links involving locations outside India. International trafficking of soft-shell turtles from or to India was almost completely restricted to Bangladesh, excepting one case that involved trafficking of soft-shell turtles from India to China (via

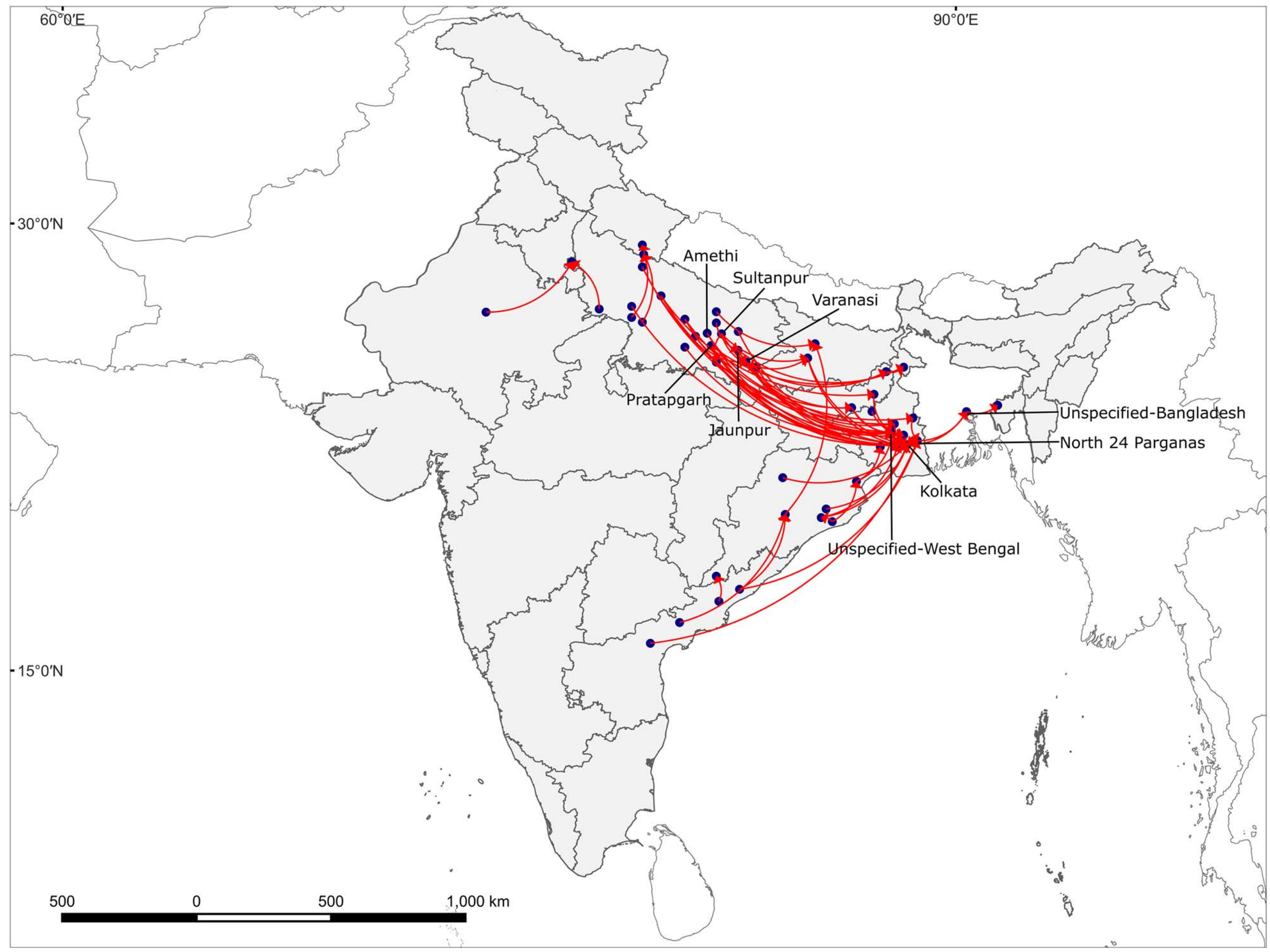

FIG. 4 Map of media-reported trafficking links involving Indian soft-shell turtles during 2013–2019. Points represent nodes (district-scale for locations within India or city-scale for locations outside India) and arrows depict the directionality of trafficking of soft-shell turtles between nodes. Only key nodes are labelled. A single incident involving trafficking of soft-shell turtles from India to Bangkok and further to Macau and Hong Kong was not included in this map for clarity of scale. Refer to Supplementary Fig. 2 for a map with a full list of labelled nodes.

Thailand). Jaunpur (in northern India) to unspecified districts in West Bengal (in eastern India) and North 24 Parganas to unspecified districts in Bangladesh were the most frequent trafficking links in this network (Fig. 2).

Regarding network-level centralization, a few nodes were more dominant in terms of incoming connections (in-degree centralization = 0.225) than outgoing connections (out-degree centralization = 0.072; i.e. a small number of

TABLE 1 Network-level metrics of the Indian tortoise/hard-shell turtle and soft-shell turtle trafficking networks.

Parameter	Tortoises/hard-shell turtles	Soft-shell turtles
Network size (number of specified & unspecified districts)	65	54
Number of unique trafficking links	75	69
Number of international trafficking links	27	5
Geographical region involved	International: India, Sri Lanka, Bangladesh, Malaysia, Thailand, Indonesia, United Arab Emirates, China	Predominantly domestic: India, Bangladesh, Thailand, China
Mean degree	2.308	2.556
Link density	0.018	0.024
In-degree centralization	0.077	0.225
Out-degree centralization	0.156	0.072
Betweenness centralization	0.038	0.013
Reciprocity	0.027	0.000

TABLE 2 Nodes with the highest degree, strength and betweenness centralities in the Indian tortoise/hard-shell turtle and soft-shell turtle trafficking networks.

Rank	In-degree	Out-degree	Degree (total)	In-strength	Out-strength	Betweenness
Tortoises/hard-shell turtles						
1	Kuala Lumpur	Chennai	Chennai	Unspecified – Bangladesh	Chennai	Chennai
2	Bangkok	Mumbai	Mumbai	Bangkok	North 24 Parganas	Kolkata
3	Mumbai, Chennai	Kolkata, Bengaluru, Anantapur, Agra	Kuala Lumpur	Kuala Lumpur	Howrah	Patna
Soft-shell turtles						
1	Kolkata	Varanasi	Kolkata	North 24 Parganas	North 24 Parganas	Kolkata
2	Unspecified – West Bengal	Jaunpur, Pratapgarh, Sultanpur	Unspecified – West Bengal	Kolkata	Amethi	Unspecified – Bangladesh
3	North 24 Parganas, Howrah	North 24 Parganas, Patna, Dhanbad, Khordha, Balasore, Visakhapatnam, Puri, Unspecified – Uttar Pradesh, Lucknow, Amethi, Bareilly	Varanasi	Unspecified – Bangladesh	Unspecified – Uttar Pradesh	Varanasi

nodes received soft-shell turtles from a large number of nodes in the network). We observed only uni-directional links between nodes in the soft-shell turtle network (reciprocity = 0). Low betweenness centralization (0.013) indicated that the betweenness centrality scores of the nodes were evenly distributed.

For soft-shell turtles, the key importing, exporting and transit nodes were all within India. The most important supply districts in terms of out-degree were located in the Gangetic plain of India: Varanasi, Jaunpur, Pratapgarh and Sultanpur. North 24 Parganas and Amethi (a district in the Gangetic plain) were identified as important supply/exporting nodes in terms of out-strength (Figs 2 & 4). The key importing nodes (in terms of incoming links and volume) were all located in eastern India: Kolkata, North 24 Parganas and unspecified districts in West Bengal. Kolkata, followed by unspecified district(s) in Bangladesh and Varanasi, also ranked the highest in terms of betweenness (Table 2).

Although there were 54 nodes in the network, removal or isolation of just one node, Kolkata, could fragment nearly 83% of the network. Several top-ranked nodes identified through other network metrics re-emerged as key players to be removed for effective fragmentation of the soft-shell turtle trafficking network (Table 3).

Discussion

In this study, we make a first attempt to examine trafficking networks involving tortoise and freshwater turtle groups in demand for different markets. We found that the tortoise/

TABLE 3 Optimal sets of nodes or key players that, when removed, can maximally fragment the Indian tortoise/hard-shell turtle and soft-shell turtle trafficking networks.

Group size	Key players	Fragmentation index
Tortoises/hard-shell turtles		
1	Chennai	0.830
2	Chennai, Mumbai	0.910
3	Chennai, Mumbai, Unspecified – Sri Lanka	0.940
4	Chennai, Kolkata, Mumbai, Unspecified – Sri Lanka	0.954
5	Chennai, Kolkata, Mumbai, Unspecified – Sri Lanka, Unspecified – West Bengal	0.961
6	Chennai, Kolkata, Mumbai, Unspecified – Sri Lanka, Delhi, Unspecified – West Bengal	0.968
Soft-shell turtles		
1	Kolkata	0.827
2	Kolkata, North 24 Parganas	0.879
3	Kolkata, Howrah, Unspecified – West Bengal	0.918
4	Kolkata, Varanasi, Howrah, Unspecified – West Bengal	0.943
5	Kolkata, Varanasi, Howrah, North 24 Parganas, Unspecified – West Bengal	0.954
6	Kolkata, Varanasi, Jaunpur, North 24 Parganas, Howrah, Unspecified – West Bengal	0.962

hard-shell turtle trafficking network (pet trade) was larger, with higher numbers of international connections and extending over a greater geographical scale than the soft-shell turtle trafficking network (meat trade). There was two-way trafficking of tortoises/hard-shell turtles between some locations, whereas we observed only one-way trafficking links for soft-shell turtles. In addition, the overall centralization differed between both networks: the tortoise/hard-shell turtle network had more dominant nodes in terms of outgoing trafficking links, whereas the soft-shell turtle network had more dominant nodes in terms of incoming trafficking links. These results suggest that tortoise and freshwater turtle trafficking networks could vary structurally according to the type of demand. A few similarities were also observed in terms of concentration of trafficking along specific geographical routes and relatively low betweenness centralization.

Our analysis of tortoise/hard-shell turtle and soft-shell turtle trafficking suggests higher levels of organization in the former compared to the latter network. The greater geographical scale and the presence of larger numbers of international trafficking links in tortoise/hard-shell trafficking could indicate the involvement of transnational criminal gangs. Moreover, the frequent use of air routes (Supplementary Table 2), which are often subject to stricter controls than land routes (Giommoni et al., 2017), potentially indicates corruption at exit and entry points, as has been observed with other wildlife products such as ivory (Wyatt et al., 2018 and references therein) and in the illegal trade of Indian star tortoises from India (Stoner & Shepherd, 2020). Additionally, a lack of training on and awareness of illegal wildlife trade amongst enforcement authorities at entry/exit points (Shepherd et al., 2007) and a lack of functional scanning equipment (Emogor et al., 2021) may also facilitate trafficking via airports. These findings contrast with soft-shell turtle trafficking, which was predominantly domestic in nature, with extensive use of road and rail transport (Supplementary Table 3). In addition, we observed convoluted smuggling routes in the form of two-way trafficking of tortoise/hard-shell turtles between specific exit points within the country, such as between Chennai and Bengaluru. This indicates dynamic use of exit points for exporting tortoises/hard-shell turtles. According to a recent investigation, Indian star tortoises, which were previously commonly smuggled out of India via Chennai, were now, because of greater risk of detection in Chennai, being predominantly rerouted from Chennai to Kolkata and from Kolkata either directly or via Bangladesh to Malaysia (Stoner & Shepherd, 2020). In contrast, the unidirectional links for soft-shell turtle trafficking indicate a simpler supply chain from source to destination, potentially necessitating less organization.

Another key result from our study is the asymmetrical roles played by some locations in both networks. Large, well-connected state capital districts such as Chennai, Mumbai, Kolkata and Bengaluru supplied tortoises/hard-shell turtles to the majority of the nodes in the network either within India or abroad. These locations have been previously implicated as major collection and distribution hubs in the illegal trade of popular pet species such as Indian star tortoises (D'Cruze et al., 2015) and spotted pond turtles (Chng, 2014; Leupen, 2019). Chennai emerged as the most central node in tortoise/hard-shell turtle trafficking, ranking as the top exporting and intermediary district, as well as being the key player with the highest potential to disrupt the network when removed. Additionally, smaller districts such as Anantapur (in southern India) and Agra (in northern India) were also important in terms of outgoing connections. Anantapur and Agra are located close to the geographical distributions of Indian star tortoises and hard-shell turtles, respectively, and may be acting as important stopover locations close to these sources before transportation to exit points within the country. Neither of these nodes were directly connected to international destinations. Similarly, corroborating our results, North 24 Parganas is also an important conduit in the land route of tortoises and hard-shell turtles being smuggled from India to Bangladesh and onwards to Southeast Asia (Stoner, 2018; Stoner & Shepherd, 2020). A few other nodes of importance that emerged through key player analysis included Unspecified – Sri Lanka, Unspecified – West Bengal and Delhi. Although the former two have been documented in previous works as transit points (Leupen, 2019; Stoner & Shepherd, 2020), the role of Delhi as a key player in this network is unclear.

Unlike tortoise/hard-shell turtle trafficking, both exporting (or supply) and importing nodes for soft-shell turtles were predominantly within India, reflecting the domestic nature of this trade. We found several districts such as Varanasi, Jaunpur, Pratapgarh, Sultanpur and Amethi lying along the Gangetic plain of the northern Indian state of Uttar Pradesh to be the key supply districts of soft-shell turtles. In surveys from the 1990s, railways followed by roads were found to be the major modes of trafficking soft-shell turtles from source locations to West Bengal in eastern India (Choudhury & Bhupathy, 1993). Our results indicate that railways and roads remain the dominant modes of transportation today (Supplementary Table 3). On the demand side, North 24 Parganas re-emerged as an important hub of soft-shell turtle trafficking, with high incoming and outgoing volumes of these turtles. Of all the districts of West Bengal that share an international border with Bangladesh, North 24 Parganas shares the second longest border (280 km) and is a documented hub of other crimes such as human trafficking, cattle smuggling and other types of illicit trade (Sarkar, 2017). Only few literature records (e.g. Pratihar et al., 2014) have mentioned the role of this district in soft-shell turtle trafficking; however, there are markets selling soft-shell turtle meat in several locations across North 24 Parganas, including Chandpara fish market, Thakurnagar market and Bongaon market, as has been reported in the media (Supplementary Material 1).

Our study provides evidence for the differences in trade operation between different groups of tortoises and freshwater turtles, which are in demand for different markets. The higher levels of complexity and dynamicity of the routes involved in the trafficking of tortoises/hard-shell turtles for the pet trade necessitate regular and consistent monitoring of trends in such trafficking by conservation and enforcement agencies. This requires inter-agency collaboration (Wyatt et al., 2020) and the involvement of expertise from cybercrime and financial crime departments. Active inter-agency and international cooperation has recently enabled the conviction of transnational criminal gangs involved in smuggling Critically Endangered tortoises and freshwater turtle species from India (Stoner, 2018; Naveen, 2021). Similarly, we identified key importing, transit and exporting nodes along the supply chains of both groups of species. Given that there were more dominant nodes in the tortoise/hard-shell turtle network in terms of outgoing trafficking links, interdiction and investigative efforts should be focused on these nodes. Surveillance at transportation facilities such as airports and seaports, railway stations, toll plazas and bus stations could be strengthened within these exporting/transit nodes (Patel et al., 2015; Cheng et al., 2017; Giommoni et al., 2017; Wang et al., 2018). Simultaneously, investigative efforts could be focused on other infrastructure facilities that may facilitate trafficking in these nodes, such as the presence of warehouses, storage facilities, captive breeding facilities or illegal hatcheries. A few unverified media reports indicate the presence of illegal hatcheries or captive breeding facilities of Indian star tortoises in a few locations in southern India (Supplementary Material 2). The central nodes in the soft-shell turtle trafficking network, however, were importing nodes, such as North 24 Parganas and Kolkata, where enforcement efforts could be focused on points of entry into these nodes (Kurland & Pires, 2017) and points of sale.

The results of our study must be interpreted with due consideration of its limitations. Given that we constructed the supply networks using media reports alone, these networks may be incomplete, because of potential incomplete reporting on seizure incidents (Mendiratta et al., 2017). In addition, the role of some locations or links could have been over- or under-represented because of variable enforcement efforts and media reporting rates across regions (Mendiratta et al., 2017; Paudel et al., 2022). For example, in our study Kolkata emerged as a key destination in the trafficking of soft-shell turtles. However, ground intelligence indicates this district only as a transit point from where soft-shell turtles are trafficked further to locations such as North 24 Parganas (A. Chaudhuri, pers. comm., 2019). This mismatch may be a result of incomplete reporting of trafficking links from sources to destinations. The situation is further complicated by the clandestine nature of illegal wildlife trade, meaning some nodes and links always remain undetected (Gregori & Merlone, 2020). More robust results for social network analysis could be obtained through integrating multiple data sources, including primary data (Hughes et al., 2017).

In this study, we show that social network analysis can be used to discern similarities and differences in different types of trade. Here we used geographical locations to study trafficking flow. Future studies focussed on offender networks could further improve our understanding of such trade. In addition, the use of other criminological tools such as crime script analysis to break down the stages and actors involved in the illegal trade chain could complement this work (Diviák et al., 2021). In both networks, a few locations and routes were used disproportionately for trafficking, but our knowledge of the characteristics of the locations and routes that facilitate illegal wildlife trade concentration remains limited. Future studies could be directed towards investigating what factors (socio-economic and cultural; presence/absence of infrastructural facilities and enforcement efforts) influence the preferences for these locations or routes over others. Such knowledge could help to predict displacement of crime when enforcement targets hotspot locations or routes, as has been explored with other types of crime (Giommoni et al., 2017, 2021).

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Author contributions Study design: RRS, AM, UM; data collection and cleaning: RRS, AM, NS, SS, AC; data analysis: RRS; writing, revisions: all authors.

Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards. This research did not involve animal or human subjects nor collection of specimens.

Data availability The data and code used for this study are available on GitHub at github.com/ramyaroopa94/turtle-trade-sna and have been archived on Zenodo at doi.org/10.5281/zenodo.8186724.

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