Biological Conservation 252 (2020) 108844

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Perspective

Mesh mash: Legal fishing nets cause most bycatch mortality of endangered South Asian river dolphins

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ARTICLE INFO

Keywords:
Bycatch mortality
Entanglement
Ganges and Indus river dolphins
Conservation
Fishery laws and regulations
Mesh sizes
Legal and illegal fishing nets
South Asia

ABSTRACT

Bycatch mortality from entanglement in fishing nets is a major threat to the conservation of endangered cetacean species, including South Asian river dolphins *Platanista*. Bycatch mortality of *Platanista* (estimated at around 5% of total population size per year) is often blamed on the use of illegal fishing gears (especially gillnets), and poor law enforcement. In our perspective paper, we found that over two-thirds of reported bycatch mortality of *Platanista* occurred in legal nets, from sources available on mesh sizes implicated in river dolphin bycatch. This finding highlights the need to critically revisit net mesh size regulations in existing fishery laws to effectively tackle the threat of bycatch. We show that minimum mesh size regulations have a colonial legacy and are a common element of fishery laws across three major range countries of *Platanista*: India, Pakistan, and Bangladesh. We also show that the existing gaps between fishery laws and wildlife conservation laws are unlikely to be helpful in prevention of bycatch. Especially in the event of accidental bycatch mortality in legal nets, enforcement of wildlife laws protecting *Platanista* can get complicated. We discuss the consequences of *Platanista* bycatch in legal and illegal fishing nets for enforcement and fishers' compliance, and explore associated factors in small-scale capture fisheries that can constrain bycatch mitigation efforts.

1. Introduction

Bycatch is a serious and pervasive threat to the conservation of endangered small cetacean species (Read, 2008; Brownell Jr et al., 2019). Bycatch mortality from entanglements in fishing gears such as gillnets has been one of the major drivers of recent or imminent cetacean extinctions, as in the case of Vaquita *Phocoena sinus*, found in the northern Gulf of California and Mexico (D'Agrosa et al., 2000; Reeves et al., 2013; Brownell Jr et al., 2019). Non-targeted mortality from fishing methods such as electric rolling hooks in the Yangtze River in China were the ultimate reason behind the extinction of the Chinese River Dolphin or Baiji (Turvey et al., 2007). Cetacean bycatch is reported from various kinds of fishing gear, which have been traditional or modern, artisanal or commercial, small-scale or large-scale, and legal or illegal (Reeves et al., 2013; Brownell Jr et al., 2019). The most commonly proposed solutions for mitigating bycatch risk (e.g. fishing gear choice, modifications, or bans) are not just ecological or technological (Komoroske and Lewison, 2015). Instead, they intersect a complex sphere of governance issues, involving legal and socio-political factors (Soykan et al., 2008; Teh et al., 2015; Whitty, 2015; Dewhurst-Richman et al., 2019), related to historic changes in ecological baselines or socio-economic trade-offs, and livelihood/conservation conflicts in small-scale or artisanal fisheries (Komoroske and Lewison, 2015; Whitty, 2015).

Fishery laws, written usually with a vision of distributive justice or fisheries sustainability, may not always align with conservation objectives and normative goals (Klug, 2002). Contradictions between fishery laws and biodiversity conservation laws can thus affect bycatch risk mitigation and management. If some fishing gears have been declared illegal and also cause bycatch, enforcement to ban such gears might appear straightforward. It is also justified to declare a particular gear illegal after evidence of increasing bycatch risk from its used has emerged. In reality, though, gear bans and enforcement of fishing regulations has proven to be difficult, even when exact mechanisms to prevent bycatch were known (as in the Vaquita case: Rojas-Bracho et al., 2006, 2019). If banning illegal gears is hard, delimiting the use of legal gears can be far more challenging, if legal gears too cause bycatch of protected cetacean species. These are tricky problems and frequently underlie discussions on cetacean bycatch reduction (Brownell Jr et al.,

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https://doi.org/10.1016/j.biocon.2020.108844
Received 22 April 2020; Received in revised form 4 September 2020; Accepted 28 September 2020
Available online 3 November 2020

2019).

Illegal (and unregulated) fisheries are often linked with negative impacts on fishery productivity (Welcomme et al., 2010). These could be through excessive harvesting, or practices that can damage aquatic habitats, (e.g. dynamite or poison use), or social impacts, e.g. links to crime. Probably due to these impacts, there appears to be a general tendency in the conservation literature to link bycatch risk specifically to the use of "illegal" gears. This assumption might lead to the belief that fishery laws are necessarily aligned with conservation laws. However, most existing fishery laws may predate acknowledgement of the bycatch problem as per today's conservation goals.

We believe that some assumptions often made about illegal fishing lack an understanding of the history of fishery laws. In many developing African and Asian regions, the category of "illegal" fishing has had colonial origins in (e.g. Malasha, 2003; Singh and Gupta, 2018). Fishery laws inherited from colonial times, have carried ideas that have persisted without much review, adaptation, or modification. Mesh sizes of nets, which are often directly linked to bycatch, offer a good example, where colonial perceptions of wasteful destruction of small fish by local fishers led to minimum mesh size restrictions (e.g. Day, 1873). Malasha (2003) and Kolding et al. (2019) show that, for inland fisheries in all British colonies as of 1953, the fisheries biologist C.F. Hickling suggested that unnecessary mesh size regulations be removed, but his advice went unheeded. There is thus a need to understand why, and in what historical context, particular fishing regulations were declared illegal, or considered "destructive" or unsustainable. In such situations, conservation interventions based on the straight enforcement of fishery laws may not be successful in reducing bycatch, as fishery laws were never intended to tackle that issue.

Here, we argue that a critical review of fishery laws inherited from colonial legacies could help us identify gaps in dealing with the problem of bycatch of endangered cetacean species. In this paper, we provide a perspective on this issue by estimating the approximate contribution of legal and illegal nets and gears to bycatch mortality of endangered South Asian river dolphins (*Platanista gangetica*, the Ganges and Indus dolphins) in the Indian subcontinent. Here we do not include intended or deliberate killing and hunting of dolphins, although *Platanista* have been hunted and consumed traditionally (Anderson, 1878; Pilleri and Zbinden, 1975; Porter and Lai, 2017; Mintzer et al., 2018). Bycatch mortality due to entanglement in fishing nets is acknowledged as one of the primary threats to *Platanista* (Mohan, 1996; Choudhary et al., 2015; Paudel et al., 2016; Braulik and Smith, 2017; Dewhurst-Richman et al., 2019). Mohan (1996) conservatively estimated that 4.4% of the total Ganges dolphin population might be dying due to bycatch mortality, at around 100 animals per year. Due to limited systematic data, it is difficult to say if bycatch mortality has increased or decreased at a regional scale since the 1990s (Braulik and Smith, 2017), but certainly continues to be a significant threat in most regions (Dewhurst-Richman et al., 2019; Kolipakam et al., 2020). In general, the absence of invested monitoring mechanisms to ensure compliance with laws (Keane et al., 2008) is thought to allow the threat of bycatch to persist. Dewhurst-Richman et al. (2019) recently estimated annual bycatch mortality of *Platanista* at 7% of the population size in the Karnaphuli-Sangu river systems of Bangladesh, and found that bycatch risk increased with larger mesh sizes and at shallower river depths. These authors focused on lack of awareness about fishery regulations among fishers and limited enforcement as major factors causing bycatch. However, they did not explicitly identify the legal status of net mesh sizes that caused bycatch mortality, similar to other recent studies on *Platanista* bycatch (e.g. Mansur et al., 2015; Kelkar, 2015; Choudhury et al., 2019; Kolipakam et al., 2020).

For our study, we conducted a review of literature on the history of inland fishery laws and regulations in the Indian subcontinent, particularly looking at legally allowed and prohibited mesh sizes and gear types. Fishing nets and gears used in the Indus-Ganga-Brahmaputra plains and delta regions are highly diverse, and involve the use of various kinds of traps, barricading nets, long-lines, hook-lines, cast nets, mono- and multi-filament gillnets, seine nets, dip-nets, mosquito nets, set bag nets, drag-nets, carpet nets, hand-nets, etc. (described in Day, 1873; Hornell, 1924; Ray, 1998; Pathak et al., 2000; Mansur et al., 2015; Braulik et al., 2015; Dewhurst-Richman et al., 2016, 2019; Paudel et al., 2016; Choudhury et al., 2019; Dey et al., 2020). We assessed rates of bycatch mortality of *Platanista* dolphins by reviewing reports of bycatch across regions of India, Nepal, Bangladesh, and Pakistan. Our null hypothesis was that there would not be any difference between bycatch proportions in legal and illegal nets. This was not a non-sense null hypothesis: even if it could not be rejected, it could have serious implications for fisheries legislation and bycatch prevention. Our alternative hypothesis, going by the commonplace argument that illegal nets are a major bycatch risk factor, was that illegal nets would account for higher bycatch proportions of the total, than legal nets. We discuss the implications of our results for the governance of small-scale riverine capture fisheries towards mitigating bycatch risk for endangered river dolphins in South Asia's riverscapes.

2. Materials and methods

2.1. History of mesh size regulations in fisheries policies

We briefly reviewed the history of fishery laws in the period from 1870 till date, across regions of the Indus, Ganga, and Brahmaputra plains. Specifically, we analysed Francis Day's (1873) Report on the Freshwater Fisheries of India and Burma, which made a strong recommendation for uniform minimum mesh size regulations across India, Bangladesh, and Pakistan (undivided India until 1947). We also reviewed other relevant literature (e.g. from Nepal) on related fishery regulations.

2.2. Literature review: fishery regulations across the study area

We reviewed all fishery laws, rules, and acts (with current relevant amendments) of the major states in India, Pakistan, Nepal, and Bangladesh, with populations of *Platanista* (Table A1 of Supplementary Material). Specifically, we scanned regulations pertaining to mesh size limits, banned gear types, and seasonal bans on the capture of breeding or migratory fishes, etc., and qualitatively assessed their implications for *Platanista* bycatch. We reviewed the available literature documenting estimates of *Platanista* bycatch rates from different regions. We also qualitatively assessed whether regional differences in bycatch were related to any legal aspects of fishery regulations (Table 1).

2.3. Estimation of proportional bycatch mortality in legal and illegal nets

We obtained mesh size information for all known and reported cases of bycatch of *Platanista* ($n = 18$) from published studies, reports, and our own field observations of bycatch cases from 2000 to 2020. Of these, 6 reports of mesh sizes were from Bangladesh, 11 from India (Bihar = 6, Assam = 3, West Bengal = 2), and 1 from Nepal (Table 2 lists sources used for each region). From Pakistan, we could not find mesh size information for dolphin bycatch cases, but fishing practices and laws in North India and Pakistan are fairly similar (see Table 1). From the mesh size limits prescribed by the fishery laws of different states, we classified bycatch cases under "illegal" and "legal" categories. We performed a weighted non-parametric resampling procedure on the small sample of mesh sizes involved in known bycatch cases (n = 18), with replacement, with 1000 randomizations. Resampling weights were calculated by multiplying the probability of bycatch risk (entanglement) in different mesh sizes (from estimates by Dewhurst-Richman et al., 2019) with the probability of use (relative frequency) of different mesh sizes in the Ganga-Brahmaputra plains from fishery assessments (e.g. Kelkar, 2008; Dey et al., 2020). Resampling with these weights helped us reduce the reporting bias in mesh sizes, and also estimate confidence intervals

Table 1
Regulations prescribed by different state rules and acts. Minimum mesh size specifications, prohibition on fishing during specified breeding seasons, seasonal bans on capture of juvenile and breeding fish, and prohibitions on particular types of fishing gears, especially fixed engines and weirs, are common features across these acts. The origin of all these regulations, except for Nepal, is in the Indian Fisheries Act (1897). Note: Bangladesh and Nepal (smaller nations) have national laws for protection of river dolphins and fisheries. In Bangladesh, fisheries are of critical importance as livelihoods for millions of people across the nation, and regional guidelines differ slightly for tidal and delta fisheries, and riverine fisheries (see Table). India and Pakistan are larger nations with state-level and provincial laws for fisheries, as inland fisheries are a 'state subject', with their importance differing significantly across different states or provinces. Pakistan also has provincial wildlife protection laws unlike the other three countries.

State	Key features of regulations relevant to bycatch	Acts and rules
Ganges River Dolphin *Platanista gangetica gangetica*		
INDIA: Ganges river dolphins are protected in India under the Wildlife (Protection) Act, 1972, and its Schedule I, which affords them the highest degree of protection. It is also designated as India's National Aquatic Animal.		
India: Uttar Pradesh	Minimum mesh sizes, fish sizes or weights below which killing or selling of prescribed fish species prohibited. Prohibit capture of or attempt to capture breeding fish in roe and milt except hilsa. Seasonal prohibitions on killing or catching or sale of any spawn, young of adult fish, of any prescribed species. Prohibited erection and use of fixed engines. Fish includes fishes, turtles, dolphins, aquatic plants of fisheries, in all states in its life history. Ban on catching, destroying, or selling fry and fingerlings (2 to 10 in. or 5 to 25 cm) from 15th July to 30th September, and breeding fish from 15th June to 30th July.	Uttar Pradesh Fisheries Act, 1948
India: Bihar	Fishing in rivers prohibited from 15th June to 15th August. Fishing net or gill net with less than 4 cm mesh size prohibited in rivers. Fishing of fingerlings of culturable fishes of any species prohibited. Putting of fence or any obstruction restricting the movement of fish prohibited in rivers and reservoirs. Use of dynamite or explosives, poison and poisonous chemicals for fishing prohibited.	Bihar Fish Jalkar Management Act, 2006, amended in 2013, 2017, 2018
India: West Bengal	Restrictions on specified area and for specified periods, fishing of specified size, group or species of fish. Ban on erection or use of fixed engines. Ban on construction, temporary or permanent, of any weir, dam or bundh. Restrictions vary on dimensions and kinds of net or size of any mesh or any other fishing contrivance, and the model of using them, according to periodic notifications. Provision for fish-pass or fish-ladder when any weir or other barrier erected for fishing. Prescribed rules to prevent harvesting of minimum age, length and weight of fish used for induced breeding, for any purpose other than scientific research.	West Bengal Inland Fisheries Act, 1984
India: Assam	Fishing by seine nets, barricading nets, gillnets, and mosquito nets with meshes less than 14 cm is prohibited from 1st May to 15th July. Length-specific restrictions for below 23 and 10 cm for ten species from September to October, including major carps, *Chitala*, *Channa*, etc. Prohibition on fishing of breeding fish and fishing with very small mesh-sized gillnets (or current jals) from 1 May to July 15.	Assam Fishery Rules, 1953, amended in 2005
BANGLADESH: Ganges river dolphins are protected in Bangladesh under the Wildlife (Conservation and Security) Act, 2012, with special mention and highest protection under schedule I of the act. The Bangladesh Wildlife Preservation Order (1973) with amendments (1974 and later) has been repealed, but also had provisions protecting Ganges river dolphins.		
Bangladesh	Restrictions and bans on current jals (fishing nets made of monofilament synthetic nylon fibre of different mesh sizes), but more specific restrictions on all other fishing nets. Ban on using fine-mesh mosquito nets and set-bag nets. Illegal nets include PL nets, monofilament gillnets, and estuarine set-bag nets with a mesh size of the cod end less than 3 cm. Minimum fish sizes of 2 cm below which no fish of any prescribed species to be killed or sold throughout the year. Prohibition of use of fixed engines, and the use or method of operation of any kind of fishing net with restricted size of meshes. Ban on gill nets with stretched mesh size <10 cm in the ilish fishery (all year). Mesh size restrictions for fishing nets vary across regions, from 3 to 10 cm, to 4.5 cm stretched mesh size for current jals, to 7.62 cm in Kaptai lake area, to below 1.5 cm to 1 in. (2.54 cm) in the Sundarbans. Ban on harvesting young ilish fish (*Tenualosa ilisha*) < 23 cm and 15-day ban on all fishing activity in September–October every year protect ilish brood stock. Fish includes all cartilaginous, bony fishes, prawn, shrimp, amphibians, tortoise, turtles, crustacean animals, molluscs, echinoderms and frogs at all stages in their life history.	The Protection and Conservation of Fish Act, 1950, East Bengal Act No. XVIII of 1950; The Protection and Conservation Fish Rules, 1985, National Fisheries Policy, 1998
NEPAL: Ganges river dolphins are protected in Nepal under the Aquatic Animal Protection Act, 1961, amended in 1999, which is also the law under which fisheries are regulated.		
Nepal	Prohibits intentional catching, killing and wounding of the aquatic animals of the species specified in that order by any person without obtaining license from Government of Nepal or the local authority, for any specified season or animal species by the act. Does not apply fully to private waters.	Aquatic Animal Protection Act, 1961, amended in 1999 (2017 BS and 2056 BS according to Nepal calendar years)
Indus River Dolphin *Platanista gangetica minor*		
INDIA: Indus river dolphins, as a subspecies of *P. gangetica*, may be interpreted to have the same legal protection status as Ganges river dolphins in India (see details above).		
India: Punjab	Seasons and prescribed minimum sizes or weights, below which the killing of any fish of any prescribed species shall be prohibited.	The Punjab Fisheries Act, 1914

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Table 1 (*continued*)

State	Key features of regulations relevant to bycatch	Acts and rules
PAKISTAN: Indus river dolphins are protected in Pakistan under provincial acts, as follows: The Punjab Wildlife (Protection, Preservation, Conservation And Management) Act, 1974; Sindh Wildlife Preservation Ordinance, 1972; and amendments till 2009, and The Sindh Wildlife and Protected Areas Act, 2010; the Khyber Pakhtunkhwa Wildlife and Biodiversity (Protection, Preservation, Conservation, and Management) Act, 2015. In all provinces, the Indus dolphin is protected under the Third Schedule, in which no hunting or possession is allowed.		
Pakistan: Punjab	Gill net size specifications stipulate minimum of 1.5 in. (3.81 cm) of each side of the mesh or total of all the sides of a mesh not less than 6 in.. Fishing with a net having a smaller mesh than the prescribed mesh is illegal. Fishing with any gear or method other than that permitted under the rules, and using more than two of either or any of the gears at any one time is not permitted. Prohibits killing fish of a size less than the prescribed size: for trout 9 in. (22.86 cm), and 12 in. (30.5 cm) for *Labeo rohita*, *Cirrhinus mrigala*, *Catla catla*, and *Labeo calbasu* (major carps) prevented from 10th October to 9th March (for trout) and from 1 June to 31 August (for major carps). Similar laws also prevail for the Khyber Pakhtunkhwa province (Table A1 of Supplementary Material).	The Punjab Fisheries Ordinance, 1961
Pakistan: Sind	Prohibits fishing by any net, cage, trap or fixed engine of capture of fish less than 12 in. for *Labeo rohita*, *Cirrhinus mrigala*, *Catla catla*, and *Labeo calbasu* (major carps) from 1 June to 31 July. Fishing with a net having a smaller mesh than the prescribed mesh prohibited attracts penalty of 100 rupees and cost of fish captured. Prohibits killing fish of a size less than the prescribed size, or more than prescribed number or during period other than permitted. Prohibits fishing with any gear or method, with more than two of either or any of the gears other than permitted under the rules.	Sind Fisheries Ordinance, 1980; Sind Fisheries Amendment Act 2011

around our estimates of legal and illegal gears accounting for bycatch. We used a binomial test to check whether the difference between estimated proportions of bycatch cases in legal and illegal net mesh sizes, was statistically significant, as per our hypotheses. We interpreted the result in relation to fishery laws and associated variables of fisheries management across different regions.

3. Results

3.1. History of mesh size regulations in the Indian subcontinent

Mesh size and gear type regulations were formalized in a sweeping way in the Indian Fisheries Act (1897), which banned the use of any "fixed engines" and "construction of weirs" to prevent indiscriminate fishing, across the Indian subcontinent. These regulations had their origins in important policy debates and recommendations from the 1870s. Day (1873) in his voluminous *Report on the Freshwater Fish and Fisheries of India and Burma* took painstaking efforts to justify the need for minimum mesh size regulations. The Report also records the opposition of

Table 2
A summary of reported bycatch mortality cases in relation to population size across different regions in the range of South Asian river dolphins *Platanista*. The highest reported rates are in Bangladesh, Bihar, and Assam, likely because of better monitoring. Nepal and Pakistan have low rates, while reporting may be low in India's West Bengal (where bycatch mortality is likely to be very high) and Uttar Pradesh (UP). A weighted sum of percentages by population size gave an overall minimum estimate of 4.75% bycatch mortality, which was close to the estimate of Mohan (1996). This is much higher than the 2% sustainable limit for mortality estimated by Dewhurst-Richman et al. (2019).

State	River systems	Bycatch mortality status	Data sources
Ganges dolphin *Platanista gangetica gangetica*			
India: Uttar Pradesh	Ganga (Bijnor to Narora)	Reported population size: 28 (2010)	Bashir et al., 2010
	Chambal (within UP)[a]	Bycatch status: low or infrequent	Hussain et al., 1993
		Reported population size: 40–50	
		Bycatch status: low, five dolphins caught in gillnets in a 70 km stretch in 1988–89. Since then bycatch cases rare as fishing is banned in most of the river.	
India: Bihar	Ganga (Bhagalpur, c.70 km) Ganga (within Bihar)	Reported population size: 150–200 (2017)	Choudhary et al., 2006; Kelkar et al., 2010; Kelkar, 2015
		Bycatch status: Estimate of 10 (~5.7% of population size) dying from entanglement in fishing nets per year.	Kelkar, 2015, Kelkar et al., 2018, field observations of authors from 2000 to 2020 in Bihar.
		Adult mortality likely to be higher than sub-adult mortality in nets.	Sinha et al., 2010 Sinha, 2006
		Reported population size: 808 (in 2006)	
		Bycatch status: 50 dolphins (~6% of population size) in Bihar estimated to die from fishery interactions per year.	
India: West Bengal	Ganga, Hooghly	Reported population size: 170–180 (2010)	Sharma, 2010
		Bycatch status: Likely to be high, especially in the Ganga and Feeder Canal near the Farakka barrage, and along the Hooghly River.	Kolipakam et al., 2020, Samad, I. (pers. comm.), recent reports, e.g. https://www.conservationindia.org/articles/bycatch-mortality-and-poaching-of-ganges-river-dolphins-in-malda-district-west-bengal
India: Assam	Brahmaputra river system[b]	Reported population size: ~900 (2017)	Kolipakam et al., 2020
	Barak	Bycatch status: High but under-reported. In 1993–94, c. 60 dolphin mortality reports. About 12 of 16 animals found dead due to bycatch in 2008 and 14 mortalities in 2004, which is around 2% of population.	Mohan et al., 1997 Wakid, 2009 Kolipakam et al., 2020 Choudhury et al., 2019
		A total of 35–45 animals (~4.5% of	

(*continued on next page*)

Table 2 (*continued*)

State	River systems	Bycatch mortality status	Data sources
		population) estimated as annual offtake for oil bait fishing. Reported population size: declined from 14 to zero animals from 1999 onwards. High: about 30 cases of bycatch mortality known between 1975 and 2015. Dolphins now extinct in the Barak, mainly from bycatch mortality and hunting in the past. Other 27 mortalities were due to targeted hunting and poaching in harpoons and seine nets.	
Bangladesh	Sundarbans	Reported population size: 196–225 (2006)	Smith et al., 1998, 2006
	Karnaphuli-Sangu basins	Between 2007 and 2013, 10 Ganges dolphins confirmed as entangled in gillnets (less than 5% of known population size). Reported population size: 170–200 High: 14 deaths per year, annual take of over 7% of local population, data from 2010 to 2012.	Mansur et al., 2008, 2015 Dewhurst-Richman et al., 2019
Nepal	Karnali and Sapta Koshi	Reported population size: 20–25 (2015) Bycatch status: Two confirmed cases between 2009 and 2015 in the Karnali (of 10 animals). Similar levels likely in the Koshi. These levels are critical because Nepal's rivers have small populations of dolphins.	Paudel et al., 2016 Khanal et al., 2016, Paudel et al., 2016
Indus dolphin *Platanista gangetica minor*			
India: Punjab	Beas	Reported population size: 5–11 Bycatch status: Likely absent. Indus Dolphins are protected in the Beas Conservation Reserve, where no fishing is allowed.	WWF-India, 2018
Pakistan: Punjab	Indus (Jinnah-Guddu barrages)	Reported population size: around 550 (2011) Bycatch status: Believed to be low at present.	Braulik et al., 2015 Braulik et al., 2015 Reeves and Chaudhry, 1998
Pakistan: Sind	Indus (Guddu to Sukkur barrages)	Reported population size: ~800 (2011) Bycatch status: Incidental captures in gillnets not uncommon. Between 1993 and 2010, about 60 in 2011–12 (~7.5% of population size), but after 2012 fishing-related mortality has been low.	Waqas et al., 2012; Braulik et al., 2015

Note:
[a] The Chambal flows along the borders of three states: Uttar Pradesh, Madhya Pradesh, and Rajasthan.
[b] Containing the Brahmaputra main stem, Kulsi River, and Subansiri River.

most provincial fishery officials to this proposal, citing zoological, political, socio-cultural, economic, practical, and even divine-religious reasons. These reasons are fascinating to read, as they explain why provincial officials thought of Day's proposed restrictions as either unnecessary or impossible to implement without major costs to fishing people.

Importantly, fishing with nets having less than mosquito-net mesh sizes was a widespread practice since the 1800s (Hamilton-Buchanan, 1812; Day, 1873; Hornell, 1924). Day reported: "There is hardly a district in India (Sind, portions of Burma, and parts of the Panjab excepted) where these fine-meshed nets are not employed as fixed engines." At best, the issue of regulating fine-meshed nets might have been moot for the Indus basin (i.e. Sind and Punjab), but not the Ganga and Brahmaputra systems where there was a predominance of fine-meshed nets. Day recommended minimum mesh size regulations of 1.25 in. (32 mm) from knot to knot for inland fishing, and a seasonal ban on catching any fish during the monsoon months (from July to October). Minimum mesh size restrictions have since persisted in fishery legislations across the Indian subcontinent (Table 1). Even in the 1870s, *Platanista* bycatch was occurring in large gillnets and seine-like fishing nets, as reported by John Anderson (1878) from Hooghly fishers.

3.2. Similarities and differences in fishery regulations in Platanista habitats

All fishery laws, across states, prescribe minimum mesh size restrictions on all nets, and bans on fixed engines, poisoning, and use of fishing weirs. Here, fixed engines refer to set bag nets, traps, barricading nets, and other stationary gears, and not to gillnets. Minimum mesh size limits varied from 40 to 100 mm, with the highest variation seen in Bangladesh, according to different regions and water bodies (Table 1). With regard to the use of fishing gears and nets with small mesh sizes, laws are variable, but prohibit indiscriminate fishing practices, and capture of breeding and migratory fish during the peak spawning season (defined variably from May to September, to cover the three-month peak monsoon period). However, regulations on capture of breeding fish were usually not linked to mesh size regulations (except for Assam; Table 1). Maximum mesh size limits were not prescribed explicitly in any other regulations. Fishing with dynamite or electro-fishing were also banned from most areas. Oil-bait fisheries, which involved the use of dolphin oil and fat, was not explicitly banned in any of the fishery acts.

The most detailed rules and regulations on fishing practices were found in fishing laws in Bangladesh and Assam (India). The level of detail then reduced in the following order: Assam and Uttar Pradesh in India, Punjab and Sindh in Pakistan, Bihar, Punjab, and West Bengal in India, and lastly, Nepal. All four countries had national and provincial wildlife conservation laws in which the highest level of protection was afforded to *Platanista* (Table 1), mostly from the 1970s onwards. Amendments to fishery laws made later did not reflect any major changes with respect to bycatch prevention of endangered species such as dolphins (Table A1 of Supplementary Material). Only the state of Uttar Pradesh in India explicitly mentioned "dolphins" as a fishery species in its fishery law (1948). In Nepal's Aquatic Animal Protection

Act (1961, and amended in 1999 and 2017), there are no specific rules or regulations on fishing practices, except for a generic ban on the intentional catching, killing, and wounding of aquatic animals. In this Act, aquatic animals are defined as "any animal living in water", but without a clear statement on whether fish are included. Importantly, the ban on capture or killing of aquatic animals did not apply in Nepal to "private waters" such as ponds, lakes, or reservoirs with private ownership (barring the use of poisonous substances). While many generic restrictions were eased, bans on indiscriminate fishing practices remained common across laws for state-controlled, public, and private fisheries (see Discussion for more details).

3.3. Bycatch mortality rates across regions

Significant variation was recorded in bycatch mortality rates across different regions (Table 2). Overall bycatch mortality across ranged from 2% to 10% of local population sizes, wherever population sizes were greater than 100 animals. These percentages were higher (~20%) for smaller populations, e.g. in Nepal. The annual percentage of bycatch mortality (weighted by reported dolphin population size) was estimated at a minimum of 4.75% of the total population (Table 2). From the sources reviewed, use of dolphin products from salvage of bycatch carcasses was found to be fairly common in West Bengal, common or infrequent but likely reducing in Bangladesh, Bihar, and Assam; and uncommon or rare in Uttar Pradesh and Pakistan, and probably absent in Nepal.

3.4. Proportion of bycatch mortality in legal and illegal nets

We estimated between 65% and 78% of the total bycatch mortality of *Platanista* to be occurring in legal gillnets. The remaining 22% to 35% bycatch mortality occurred in gillnets with small mesh sizes or seine nets (illegal), or other legal gears such as set bag nets and long lines. Differences between resampled estimates were statistically significant (binomial test: $P < 0.001$) from the null expected probability of 0.5 (equal proportions of bycatch cases in legal and in illegal nets). These estimates included both flood-season and dry-season mortality due to bycatch. Median mesh size was 70 mm with a standard deviation of 40 mm.

4. Discussion

Our results revealed that over two-thirds of the existing bycatch mortality of *Platanista* might be occurring in legal nets, which was a surprising finding. More data on mesh sizes implicated in river dolphin bycatch is needed from future studies to validate this relationship. Our initial findings still provide an interesting insight, because of their implications for fisheries management, law enforcement to prevent bycatch, and river dolphin conservation. The riverscapes in which *Platanista* live are multi-use systems with intensive competing human demands on water for irrigation, urban and rural supply, power generation, navigation, fisheries, and ecology (Reeves et al., 2000; Braulik and Smith, 2017). Bycatch mitigation is thus also a joint management problem across different state departments (e.g. fisheries, wildlife, water resources, etc.). In implementing conservation interventions, legal considerations are inevitable, and fishery laws and conservation goals can be in conflict (e.g. see Kolding et al., 2014). Ensuring that only legal nets are in use in riverine fisheries may not necessarily reduce bycatch risk for *Platanista*.

There is then the issue of legal priority, i.e. what laws should apply before others in this kind of problem. It can be argued that bycatch amounts to the death of a legally protected species and fishermen involved must be penalized accordingly. But due to the "accidental" nature of bycatch, proving intent or motive is not easy. Thus the act of having killed a protected, endangered species may be illegal, but its unintended nature, in a legally allowed fishing net, can complicate legal procedure for conviction or penalization, and therefore limit the success of enforcement for conservation, which may be easier in cases of deliberate killing or hunting. For example, Pakistan has been the most successful in enforcing the ban on hunting dolphins, and has the lowest reports of bycatch (Braulik et al., 2015). Pilleri and Zbinden (1975) had also noted that targeted hunting and habitat loss were major reason for population declines, and not bycatch, which was at best a smaller threat (Reeves and Chaudhry, 1998). In most cases, proving what is actually "accidental" or "intended" is difficult, with these categories being almost inseparable according to Sinha (2002). He defined "assisted incidental capture", wherein fishers placed nets in ways that would entangle dolphins 'by accident'. In the case of *Platanista*, a fisherman might as well use the oil from the entangled carcass as bait than report the event and bear the risk of being penalized or convicted under wildlife laws. Non-intended, non-targeted takes of "aquatic wild meat" from bycatch cases (Robards and Reeves, 2011; Mintzer et al., 2018) also needs to be addressed by fishery laws and not just wildlife laws.

Existing mesh size regulations in the Indian subcontinent prohibit fishing with nets or gears with mesh sizes below minimum prescribed sizes. The purpose of these regulations is to prohibit the capture of small and immature fish, for the sake of fisheries sustainability. Nets with mesh sizes below 30–40 mm, while illegal, might cause lower bycatch. Although many studies indicate that adult *Platanista* are at risk from nets with larger mesh sizes (Kelkar, 2008; Bashir et al., 2010; Khanal et al., 2016; Paudel et al., 2016; Kelkar, 2018; Choudhury et al., 2019; Dewhurst-Richman et al., 2019), our paper is the first to analyse the correlation between bycatch risk and legality or illegality of nets.

Adult dolphins may be able to often break free of larger meshed nets and escape (Dewhurst-Richman et al., 2019). Reeves et al. (2000) cited Sinha's observations in the Ganga river as: "small-mesh monofilament plastic nets cause the greatest damage because of their extensive use and because dolphins cannot break free of them once entangled". Anderson (1878) noted in the Hooghly River that: "*Platanista* is not unfrequently captured in the nets of the fishermen, but such an event is not considered a cast of fortune, for the animal, in its struggles to escape, seriously damages the nets, which are not adapted for entrapping such unwieldy and powerful mammals." Sinha (in Reeves et al., 2000) reported that the incidence of entanglement changes seasonally for different age classes. Juveniles and young adults were most susceptible to bycatch-related mortality, getting caught in nets set in shallow waters during the onset of the monsoon, while adults were caught in the dry season in the main channel. However, these observations did not mention numerical ranges of small and large mesh sizes. Calves and sub-adults also dominated dolphin bycatch mortality cases from 1975 to 2015 in the Barak River in Assam (Choudhury et al., 2019). In contrast, our long-term observations (2000−2020) on bycatch mortality from the Ganga River in Bihar (reported in Choudhary et al., 2006, 2015; Kelkar, 2015; Kelkar et al., 2018; Dey et al., 2020) found higher rates of adult mortality than sub-adults and calves, and a higher proportion of male dolphins than females. Gillnets with large mesh sizes drifted down the main channel were especially risky for adult dolphin bycatch mortality in the dry-season. Pregnant or lactating females may also be highly susceptible to bycatch mortality in the peak breeding season (April to June). Anderson (1878) reported pregnant females and females with calves to get caught in nets between March and September. Today, in 2020, almost all gillnets are made of nylon and plastic monofilament or multifilament. Changes in net material from natural fibres to nylon and synthetic fibres might have significantly increased adult and sub-adult dolphin mortality, as dolphins may find it harder to break these nets.

Large gillnets don't just kill adult dolphins. They also selectively harvest large-sized breeding fishes, and can negatively affect recruitment (Birkeland and Dayton, 2005). In turn, excessive fishing with small mesh sizes (e.g. mosquito nets) used in the receding flood-season (de Graaf et al., 1999) could affect fish stocks by preventing growth to maturity. Mosquito-net use in fisheries is increasing worldwide, but scientific assessments of their impacts are limited (Short et al., 2018).

The fact that such nets were historically in regular use points to a critical re-assessment of their illegal status. Mosquito nets are also selective for small fishes, and might even contribute to balanced harvesting in inland fisheries, rather than cause 'destruction' of immature fish (see Kolding and van Zwieten, 2011; Tilley et al., 2020). Abbott and Campbell (2009) describe similar conflicting views on the use of mosquito nets in Zambian fisheries. But further discussion on the issue of balanced harvesting or growth overfishing vis-à-vis legal limits on the use of fine-meshed nets (e.g. Kolding and van Zwieten, 2011; Plank et al., 2016; Pauly et al., 2016; Tilley et al., 2020) is beyond the scope of this paper.

Gillnet mesh sizes have also reduced over time as large fish have declined due to selective removal by fisheries, and catches are increasingly dominated by low-trophic, small fish species in the Gangetic plains (Kelkar, 2008, 2018), conceptualized as a "fishing down" process by Welcomme (1999), and discussed by Kolding et al. (2019). Kelkar et al. (2010) also noted a trend of reducing fishing effort with large dragnets and large-meshed gillnets (e.g. 120 mm+) in Bihar's Gangetic plains. Reduction in the use of large nets has also occurred as many fishers have quit fishing and migrated for non-fishing labour or work opportunities (Kelkar, 2018). Passive and sedentary fishing gears (traps, stake-nets, etc.) are, however, increasing significantly. Fixed engines mostly use fine-meshed mosquito net cloth, and thus can be termed illegal. Harvests of small fish by such nets might reduce local prey availability for Ganges river dolphins (Mansur et al., 2015; Kelkar and Krishnaswamy, 2014). Small-meshed nets (<40 mm) also kill dolphins and result in bycatch, but the proportion they account for appears to be smaller than large-meshed nets (Kelkar, 2018). With greater use of small-meshed nets, bycatch mortality may shift to sub-adults or young adults from adult dolphins. Bycatch might even reduce if passive and sedentary traps (see above) start to dominate fishing effort. In this scenario, population-level impacts of illegal nets on *Platanista* might be relatively lower than impacts of legal nets! As large and commercially valuable fish species have also been reducing, fishers have been demanding a lowering of the minimum mesh sizes legally allowed. Choudhary et al. (2006) cite the demand of fishers in Bihar for a new legal lower limit of 24 mm, so that the nets that give them optimal harvests today are not considered illegal. If this demand to lower the minimum mesh size were conceded, it would inflate our estimated proportion of dolphin bycatch from "legal" nets. Mitigating bycatch risk to *Platanista* may require amendments to existing fishery laws to introduce maximum mesh size limits and seasonally optimal size-limits as well, apart from net and gear modifications or allowances to comply with minimum bycatch targets (Raby et al., 2011).

The legal conundrum of bycatch mortality due to accidental entanglement in gillnets also has institutional and political economic dimensions. Who controls the fishery and under what (historic and present) property rights and access regimes, can bear upon how the legal issues surrounding bycatch risk in fishing nets could be addressed. Large floodplain regions within the Indus and Ganga plains were under private or state-controlled auction-lease systems for river fishing (Reeves, 1995; Pokrant et al., 2004; Singh and Gupta, 2018). Auction-lease systems in river fishing continue in Punjab (Pakistan) and Uttar Pradesh (India). Sindh (Pakistan) and Bihar (India) have regimes resembling "open-access" (Kelkar and Krishnaswamy, 2014; Braulik et al., 2015). In West Bengal, Assam, and Bangladesh, fishing is organized today under different access regimes, from private or state control to open-access to cooperative management (Pokrant et al., 2004; Chandra and Bhattacharyya, 2016; Dewhurst-Richman et al., 2016; Kelkar, 2018). The differential consequences of these regimes on compliance with fishing regulations and bycatch need to be studied further.

Our perspective paper demonstrates how the implementation of plans to mitigate bycatch risk of South Asian river dolphins can be complicated by the legality of nets and gears used in small-scale fisheries. We emphasize the need to unpack the categories of legal and illegal fishing in a historical sense, than just deal them with an enforcement-oriented approach. We suggest that there is scope to amend current fishery laws in the context of minimizing river dolphin bycatch risk. Adaptive species- and size-based regulations, and risk-based quota and insurance systems (Holland, 2010; Komoroske and Lewison, 2015) rather than blanket bans on minimum mesh size, will be more prudent (but also complex to implement). Local state and non-state institutions, and not law enforcement alone, would play a key role in minimizing bycatch risk. Effective governance of capture fisheries of South Asian river-floodplain systems is linked to reforming the access regimes in which fisheries across these river basins are being worked (Choudhary et al., 2015; Kelkar, 2018). It is here that strong collaborations between state fisheries and wildlife departments, fishing communities, conservationists, scientists, and civil society will be needed for effective governance. In the absence of such governance, legal enforcement solutions to reduce bycatch could get entangled in their own meshwork and remain with loopholes.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2020.108844.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This paper contributes to partial fulfilment of the publication requirements of the Ph.D. thesis of Nachiket Kelkar at the Manipal Academy of Higher Education. We thank Sunil Choudhary, Jagdish Krishnaswamy, Sushant Dey, and Rohan Arthur for their insights on some perspectives we have presented in the paper. We wish to thank all the fishers who have been our long-term collaborators and critics, for their support over the years. We sincerely acknowledge the funding support from the Duleep Matthai Nature Conservation Trust, International Whaling Commission's Small Cetacean Fund (2013), and the Ravi Sankaran Inlaks Small Grants Program (2012). N.K. thanks the Ashoka Trust for Research in Ecology and the Environment (ATREE), and S.D. thanks the Wildlife Institute of India CAMPA project, for institutional support. We thank the anonymous reviewers and the editor for their constructive suggestions and positive feedback.

Author contributions

Nachiket Kelkar conceptualized the article, conducted the research and literature review, compiled and analysed data, and wrote the paper. Subhasis Dey conducted the research and literature review, compiled data, and helped in developing the ideas presented in the perspective article.

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