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Review Article

Incidental Catch of Marine Mammals and Turtles in Gillnets: Indian Scenario

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Abstract

Gillnets contribute significantly to the livelihood of a major category of fishers, particularly in the artisanal sector. While gillnet is considered as a selective and responsible gear, there is serious concern worldwide due to incidental catch of marine mammals, marine turtles and other large marine organisms in the gear. Such incidental catch is identified as the main reason for the injury, mortality and even decline of certain populations. Very little research has been done on the issue of incidental catch of mammal and turtle in gillnets from Indian waters. The present communication gives an introduction to gillnets in India, the environmental impacts of gillnetting and reviews the incidental catch of marine mammals and turtles in gillnets and also identifies mitigation measures and knowledge gaps in addressing these issues. Gillnets affect mammals and turtles through entanglement and ingestion of gear or gear parts. The increasing number of gillnet fishing units and the upward trend in length and vertical height of the nets deployed are likely to increase marine mammal and turtle interactions with gear in future. We suggest regular monitoring of this fishery, with special reference to incidental catch of marine mammals and turtles. Regulation of gillnet fishing effort in terms of size and number of gears along with continued research to develop mitigation strategies and policy guidelines at the national level would ensure responsible gillnet fishing.

Keywords: Gillnet, bycatch, mammals, turtles, mitigation

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Introduction

Gillnet is one of the oldest and the simplest type of fishing gear operated world-wide both in inland and marine water bodies. It is basically a wall of netting, rectangular in shape, kept vertically in water body by means of floats on the upper side and sinkers on the lower side (Thomas, 2001). It is a passive fishing gear that is not actively moved by humans or machines while the fishes are being captured. Gillnet is an almost invisible panel of netting and fish swim into it without noticing it and are caught behind the gill cover and then cannot back out, hence the term "gillnet" (He, 2006). It is a versatile gear which can be operated at the surface, column or bottom layers of the water column. Simplicity in design, construction, operation and low operating cost, along with the ability to operate from different classes of vessels, or even without the aid of a vessel, make it a favourite choice among fishers. It is a low energy fishing method as it consumes between 0.15 and 0.25 kg fuel to catch one kilogram of fish against 0.8 kg of fuel consumed by trawl, an active fishing gear (Gulbrandson, 1986; Suuronen et al., 2012).

The selective property of gillnets allows it to catch fish of desired size class by optimizing the mesh size of the net. Gillnets are mostly made of synthetic fibres mainly nylon (Polyamide) monofilament or multifilament. In earlier days, gillnets were constructed of natural fibres such as cotton. During late 1950s, with the introduction of synthetic fibres having good resistance to rotting, high breaking strength, high abrasion resistance and low maintenance cost, natural materials began to be replaced with synthetic fibres for the fabrication of gillnets (Thomas & Sandhya, 2019).

Among India's total fishing fleet of 1,94,490 vessels in 2010, 67% are constituted by gillnet vessels comprising of 19, 850 mechanised, 61, 873 motorised and 49,435 non-motorised vessels and gillnets constitute 83% of the 5.1 million fishing units operated (Thomas et al., 2020a). This highlights the importance of this fishing gear in the Indian fishing sector. Gillnet operations contribute to more than 15% of country's total landings (Sathianandan, 2013). Currently in India, gillnets provide livelihoods for an estimated 0.86 million people and contribute significantly to fish catch, income and food security, as well as the local and national economy (Thomas et al., 2020a). Gillnet fisheries of India is classified into non-motorised, motorised and mechanised sub-sectors, based on size of the vessel and method of propulsion. According to mesh size, gillnets are categorised as small (<45 mm), medium (between 45 and 70 mm) and large (>70 mm) mesh (DAHDF, 2005). The non-motorised subsector operates small and medium mesh gillnets from wooden and FRP canoes and fishing is confined to single day operations in the coastal and near-shore waters, targeting sardine, mackerel, shrimp, mullets, catfish, anchovies, crabs and other species. The motorised gillnet sector consists of two categories *viz.,* vessels undertaking (i) single day fishing trips and (ii) multiday trips. Those vessels undertaking single day fishing operation fitted with outboard motor (OBM) of upto 15 hp carry small and medium mesh gillnets and trammel nets onboard, targeting mainly mackerel, sardine, anchovy, shrimp and pomfret. Another category of motorized vessels fitted with 15 to 28 hp OBM undertake multiday fishing of 3-5 days, targeting seerfish and tuna, using large mesh gillnets. The mechanized gillnet sub-sector comprises of wooden, FRP or steel vessels powered with 24 to 280 hp inboard diesel engines targeting tuna, seer, sailfish and shark using large mesh gillnets and undertake multiday trips extending 15 to 45 days (Thomas et al., 2020a).

Introduction of synthetic netting, mechanised propulsion of fishing vessels and introduction of outboard motors (OBMs) revolutionized the Indian gillnet fishing industry. In 1990s there was a switching over of gillnet material from polyamide (nylon) multifilament to polyamide monofilament in almost all small and medium mesh gillnets and a major portion of large mesh gillnets except those targeted for tuna, seerfish and other large pelagics (Pravin & Ramesan, 2000; Thomas, 2001).

Worldwide, gillnets and purse seines are identified as the major gears causing mortality of marine mammals (Perrin et al., 1994; Wise et al., 2001; Read et al., 2006). Several issues associated with gillnets are due to the steady increase in fishing effort *viz.,* increase in size of vessel and engine power, large volume of net deployed, long fishing time and soaking time (Thomas, 2020b). In India, based on available records, mortality of marine mammals are mostly due to entanglement/incidental catch in gillnets (Jeyabaskaran & Vivekanandan, 2013; Jeyabaskaran et al., 2016). There has been a significant increase in the quantity of nets taken for operation over the last five decades in India indicating a significant increase in the fishing effort (Thomas, 2010). The rising number and efficiency of mechanized vessels further augmented the chances of encounters of fishing gear with marine mammals (Jeyabaskaran et al., 2016). Gillnets were also reported as a major threat to marine turtles in different parts of the world (Gillet, 2011; Lewison et al., 2014). In India too, incidental capture in gillnets has become a serious threat to sea turtle populations (Rajagopalan et al., 1996; 2001; Pandav & Choudhury, 1999; Wright & Mohanty, 2002; Bhupathy & Saravanan, 2006). Rajagopalan et al. (2001) reported that gillnets accounted for 76.8% of turtles landed or trapped along the Indian coast.

Environmental impacts of gillnet fishing

Gillnets are considered as resource specific, highly selective and eco-friendly fishing gear having very low environmental impacts, catching a narrow size range of fishes. However, these advantages attributed to gillnets began to be lost by early 1990s due to the incidences of bycatch of marine mammals, turtles and sea birds in high sea drift gillnets (Northridge, 1991). Selectivity of gillnets mainly depends on the mesh size and gear configuration, which in turn is influenced by the looseness of the net. Netting in gillnet is usually rigged to head rope with a hanging coefficient ranging between 0.45-0.7 mostly around 0.5, which determines the looseness of the netting and thereby the shape and opening of the mesh (Thomas, 2010). Rigging nets at a hanging coefficient of less than 0.5 is common in marine drift gillnets and these loosely hung nets entangle non-target species including threatened and endangered marine organisms (Thomas et al., 2020b). Specialized gillnets for oceanic fishing rigged without foot rope and even sinkers give all the chances for catching fish by entangling. These nets when allowed to drift with wind and current, tend to gill, entangle and enmesh a wide range of organisms like marine mammals, turtles and birds (Thomas, 2010).

Apart from bycatch, the problem of lost gillnets is another area of concern. Lost, abandoned or otherwise discarded fishing gear termed as ALDFG, drifts with wind and waves and entangle marine animals leading to ghost fishing. Ghost fishing is the ability of lost gears to continue capturing fish and other marine organisms after fishers lose control of the gear and results in their unaccounted mortality (Smolowitz, 1978; Matsuoka et al., 2005). Gillnets are more likely to become ALDFG and do ghost fishing especially with the introduction of synthetic fibers which take years to degrade. These lost fishing gears may continue to catch fishes and other organisms for several years before they become inactive (Smolowitz, 1978). Ghost fishing by gillnets has impacts on various aquatic organisms such as fishes, sea birds, mammals, benthic organisms and with some of the greatest impacts on turtles (Wallace et al., 2013; Duncan et al., 2021). Increased use of monofilament gillnets is reported to cause more interactions with marine mammals (Mitchell 1975; Gaskin, 1983). Deployment of very long nets and extensive use of monofilament gillnets by fishers, pose high risks of gear loss and consequent ghost fishing in Indian waters (Thomas, 2010). Reports on ALDFG and ghost fishing from Indian waters are limited (Thomas et al., 2019). A pioneering study by ICAR-CIFT in 2017-18 on ALDFG in Indian waters relating to gillnets and trammel nets 6 covering 12 locations in 4 states (Andhra Pradesh, Gujarat, Tamil Nadu & Kerala) indicated a loss of 24.8% of the total weight of gear used per vessel per year (Thomas et al., 2020a), indicating the severity of the issue. In the light of estimates on fishing sector alone contributing to 65% of the sea-based sources of marine litter (Arcadis, 2012), the quantum of gear loss from Indian gillnet sector is to be noted seriously (Thomas et al., 2020b).

Marine mammal incidence

As early as in 1980s, there had been reports on fishing gear and cetacean interaction (Northridge, 1984). Dolphins, whales and other cetaceans were reported to get entangled in fishing nets especially tuna gillnets (Northridge, 1991; Perrin et al., 1994). Cetaceans mostly get entangled in gillnets when they deprade on the catch. Read et al. (2006) estimated that 84% of global cetacean bycatch was due to gillnetting. Anderson (2014) estimated the cetacean bycatch from tuna gillnet fisheries in the western and central Indian Ocean alone around 60,000 per year. Gillnets pose the greatest risk of bycatch for several marine mammals and chances of entanglement are more in surface drift nets (Read et al., 2006; Reeves et al., 2013; Peltier et al., 2020). A 2006-2008 study reported that approximately 6900 harbour porpoises were caught in monk and cod gillnets per year in the Norwegian waters (Bjørge et al., 2013). Because of the issue of bycatch of marine mammals in large scale driftnets, the United Nations Resolution 44/225 passed in 1989 banned driftnet fishing using nets of more than 2.5 km length in the high seas (He, 2006). Though this ban is in place, the practice of using large driftnets continues in many countries, including India. Endemic cetacean vaquita porpoise reached near extinction in Mexico due to gillnets and a gillnet ban had been recommended (Taylor et al., 2017). Dolphins often are found enmeshed in gillnets while predating on entangled fish (Romanov et al., 2014) and their slower movement close to surface waters, less alertness and poor net detection ability might be the reasons for their high entanglement in gillnets (Maigret, 1994).

Over the last five decades, there has been significant expansion of gillnet fisheries in India in terms of number and fishing capacity of the vessels which in turn resulted in an increase in the quantity of gillnets taken for operation (Thomas, 2010). The growing size of the gillnets from around 800 m in 1960s to more than 10 km augmented the chances of marine mammal encounters. From Indian seas, 26 species of cetaceans and one species of Sirenian have been recorded and all these 27 species are protected under the Indian wildlife protection act, 1972 (Vivekanandan et al., 2010; Jeyabaskaran et al., 2016). Capture and trade of marine mammals are punishable under the Act. Eventhough the Act has helped to reduce intentional catch of the mammals, their incidental catch in fishing gears is a major concern (Jeyabaskaran et al., 2016). The incidental mortality of marine mammals due to interaction with gillnets has not been regularly monitored and only occasional reports and observations are available. Examples of recorded incidental catch of marine mammals in gillnets from Indian waters are depicted in Table 1.

Different species of dolphins, whales, one species of porpoise (finless porpoise, *Neophocaena phocaenoides*), and sea cow (*Dugong dugon*) form major portion of

Table 1. Examples of recorded incidental catch of marine mammals in gillnets from Indian waters

Year	Mammal species	Location	Reference
1974-1976	Sea cow, *Dugong dugon*	Ross Island, Durgapur, Abardeen Jetty, Campbell Bay, Magar Nallah, Lakshman beach, Andaman Nicobar Islands	D'souza et al., 2010
1976-1980	Spinner dolphin, *Stenella longirostris*, Indo-Pacific bottlenose dolphin, *Tursiops aduncus,* Indo-Pacific humpback dolphin, *Sousa chinensis* and Short-beaked common dolphin, *Delphinus delphis** Finless porpoise *Neophocaena phocaenoides*	Off Calicut coast, Kerala	Lal Mohan, 1985
1971-1975	Sea cow, *Dugong dugon*	Gulf of Mannar and Palk Bay, Tamil Nadu	Lal Mohan, 1976
1974-1976	Sea cow, *Dugong dugon*	Ross Island, Durgapur, Abardeen Jetty, Campbell Bay, Magar Nallah, Lakshman beach, Andaman Nicobar Islands	D'souza et al., 2010
1976-1980	Spinner dolphin, *Stenella longirostris*, Indo-Pacific bottlenose dolphin, *Tursiops aduncus,* Indo-Pacific humpback dolphin, *Sousa chinensis* and Short-beaked common dolphin, *Delphinus delphis** Finless porpoise *Neophocaena phocaenoides*	Off Calicut coast, Kerala	Lal Mohan, 1985
1976	False killer whale, *Pseudorca crassidens*	Port Blair, Andamans	James, 1984
1977	False killer whale, *Pseudorca crassidens*	Port Blair, Andamans	Sivaprakasam, 1980
1978	Indo-Pacific humpback dolphin, *Sousa chinensis*	Calicut, Kerala	James & Lal Mohan 1987
1980, 1981	Indo-Pacific bottlenose dolphin, *Tursiops aduncus*	Off Calicut coast, Kerala	Lal Mohan,1982
1981	Indo-Pacific humpback dolphin, *Sousa chinensis*	Off Calicut coast, Kerala	Lal Mohan, 1983
1982	Short-beaked common dolphin, *Delphinus delphis**	Thonithurai and Krusadai Island near Mandapam, Tamil Nadu	Pillai & Kasinathan, 1987
1981-1987	Spinner dolphin *Stenella longirostris*, Indo-Pacific bottlenose dolphin *Tursiops aduncus*, Short - beaked common dolphin, *Delphinus delphis* * and Indo-Pacific humpback dolphin, *Sousa chinensis* Finless porpoise, *Neophocaena phocaenoides*	Cochin, Kerala	Jayaprakash et al., 1995
1982-1987	Short-beaked common dolphin, *Delphinus delphis**	Sakthikulangara, Kerala	Pillai & Chandrangathan, 1990
1983-1988	Sea cow, *Dugong dugon*	Little Andaman, Ross Island, Sound Island, Long Island, Paschimsagar, Laful bay, Lakshman beach, Andaman & Nicobar Islands	D'Souza et al., 2010
1983-1984	Sea cow, *Dugong dugon*	Kilakarai and Periapattinam, Gulf of Mannar, Tamil Nadu	Silas & Fernando, 1985

1985	Minkewhale, *Balaenoptera acutorostrata*	Kakinada, Andhra Pradesh	Rao, 1991
1986	Short-finned Pilot whale, *Globicephala macrorhynchus*	Pudukuppam, Cuddalore, Tamil Nadu	Nammalwar et al., 1989
1988,1990,1992	Finless porpoise, *Neophocaena phocaenoides*	Mandapam, Pillaimadam and Rameswaram, Tamil Nadu	Nammalwar et al., 1994
1989	Striped dolphin, *Stenella coeruleoalba*	Off Parangipettai, Tamil Nadu	Kumaran, 2003
1990	Sei Whale, *Balaenoptera borealis*	Palk Bay, Tamil Nadu	Pillai et al, 1995
1991	Spinner dolphin, *Stenella longirostris*	Visakhapatnam, Andhra Pradesh	Rao & Rao, 1992
1992	Finless porpoise, *Neophocaena phocaenoides*	Porto Novo (Parengipettai), Tamil Nadu	Kumaran, & Subramaniam, 1993
1992	False killer whale *Pseudorca crassidens*	Off Veerpandianpatnam, Gulf of Mannar, Tamil Nadu	Kasim et al., 1993
1993	Indo-Pacific humpback dolphin, *Sousa chinensis*	Calicut, Kerala	Lal Mohan, 1995
1993	Spinner dolphin *Stenella longirostris*	Lawson's Bay, Visakhapatnam, Andhra Pradesh	Rao & Chandrashekar, 1994
1994	Indo-Pacific humpback dolphin, *Sousa chinensis*	Off Tuticorin, Tamil Nadu	Arumagam et al., 1995
1994	Blue whale, *Balaenoptera musculus*	Mangamaripeta, Visakhapatnam, Andhra Pradesh	Mohanraj et al., 1995
1995-1997	Sea cow, *Dugong dugon*	Periapattinam, Seeniappa Darha, Muthupettai, in Gulf of Mannar, Alagakulam in Palk Bay, Tamil Nadu	Badrudeen et al., 2004
1995	Spinner dolphin, *Stenella longirostris*, Indo-Pacific bottlenose dolphin, *Tursiops aduncus,* Indo-Pacific humpback dolphin, *Sousa chinensis* and Short-beaked common dolphin, *Delphinus delphis*	Calicut, Kerala	Lal Mohan, 1995
1995	Spinner dolphin, *Stenella longirostris*	Kovalam, Kanyakumari, Kerala	Pillai, 2002
1997	Indo-Pacific humpback dolphin, *Sousa chinensis*	Murud-Janjira, Maharashtra	Jadhav & Rao, 1998
1997	Indo-Pacific humpback dolphin, *Sousa chinensis*	Veraval, Gujarat	Kizhakudan et al., 1998
1999	Irrawaddy dolphin, *Orcaella brevirostris*	Chilika lake, Odisha	Sinha, 2004
2000	Sea cow, *Dugong dugon*	Tharuvaikulam, Gulf of Mannar	Badrudeen et al., 2004
2001	Finless porpoise, *Neophocaena phocaenoides*	Sangumal (Palk Bay) near Rameswaram, Tamil Nadu	Kasinathan, 2002
2001	False killer whale, *Pseudorca crassidens*	Ennore along the Chennai coast, Tamil Nadu	Nammalwar et al., 2002
2002	Finless porpoise, *Neophocaena phocaenoides*	Rameswaram, Tamil Nadu	Bose, & Palanichamy, 2003
2004	Spinner dolphin, *Stenella longirostris,* Indo-Pacific humpback dolphin, *Tursiops aduncus,* Spotted dolphin *Stenella attenuata,* Long-beaked common dolphin *Delphinus capensis,* Indo-Pacific humpback dolphin *Sousa chinensis,* Risso's dolphin, *Grampus griseus*	Chennai, Kakinada and Mangalore fishing harbours	Yousaf et al., 2009

2004	Spinner dolphin, *Stenella longirostris*	Chennai, Tamil Nadu; Kakinada, Andhra Pradesh	Yousaf et al., 2010
2004 & 2005	Indo-Pacific humpback dolphin, *Sousa chinensis,* Long-beaked common dolphin, *Delphinus capensis,* Spinner dolphin *Stenella longirostris,* Indo-Pacific humpback dolphin, *Tursiops aduncus,* Risso's dolphin, *Grampus griseus*	Mangalore, Malpe and Gangoli in Karnataka ; Chennai, Tamil Nadu	Anoop et al., 2008
2005	Finless porpoise, *Neophocaena phocaenoides*	Malpe, Karnataka	Jayasankar et al., 2008
2010	Irrawaddy dolphin, *Orcaella brevirostris*	Chilika lake, Odisha	Jayasankar et al., 2011
2012	Spinner dolphin, *Stenella longirostris*	Dummulapeta, Andhra Pradesh	Prabhakar et al., 2014
2013	Spinner dolphin, *Stenella longirostris*	Mangalore, Karnataka	Bindu et al., 2014
2013	Sea cow, *Dugong dugon*	Gulf of Mannar & Palk Bay, Tamil Nadu	Sivakumar & Nair, 2013
2011-16	Dolphins (species not specified)	Veraval, Gujarat	Koya et al., 2018
2015	Dolphins (species not specified)	Tamil Nadu, Kerala and Gujarat	FAO, 2017
2017	Sea cow, *Dugong dugon*	South Pudukudi, Pudukkottai district in Palk Bay area.	Vinothkumar et al., 2017

**Specimens reported in the cited literature as Delphinus delphis are to be considered as Delphinus capensis* (Kumaran, 2002 & 2012; Sathasivam, 2004; Jayasankar et al., 2008).

incidental catch in gillnets. The incidence of cetacean bycatch in tuna and seerfish gillnets in India, has been recognized since 1980s (Sivaprakasham, 1980; Lal Mohan, 1982, 1983 & 1985; James, 1984). India ranks third among Indian Ocean countries in tuna landings and correspondingly has sizeable cetacean bycatch (Anderson et al., 2020). Two species of dolphins usually reported as bycatch in the gillnet fishery are the spinner dolphin, *Stenella longirostris* and Indo-Pacific bottlenose dolphin, *Tursiops aduncus* (Table 1). Other species such as Risso's dolphin, *Grampus griseus*, long-beaked common dolphin, *Delphinus capensis* and Indo-Pacific humpback dolphin, *Sousa chinensis* are also reported (Vivekanandan et al*.,* 2010; Jeyabaskaran et al., 2016). As a result of motorisation and mechanisation, there has been a shift in gillnet operation from inshore to offshore waters/ high seas. Thus, there is a possibility of change in the species composition of cetacean bycatch in drift gillnets which has not been properly documented (Anderson, 2014). As per Anderson et al. (2020), in India, finless porpoise, Indo-Pacific Humpback dolphin and Indo-Pacific bottlenose dolphin must have been caught in tuna/seer gillnets operated in inshore waters while spinner dolphin, Risso's dolphin and dwarf sperm whale among other species dominated the offshore drift gillnet bycatch. Yousuf et al*.* (2009) also reported spinner dolphin and bottle nose dolphin as the most common species incidentally caught in gillnets in India.

Lal Mohan (1994) estimated the annual cetacean mortality caused by the Indian gillnet fishery as 1000–1500. Later, Yousuf et al*.* (2009) estimated that 9000-10,000 cetaceans were killed by gillnets, mainly in tuna gillnets, every year along the Indian coast by extrapolating data from three landing sites along the coast stating that this could be an underestimation as observations were limited to only 3 h a day. Maximum number of dolphin entanglements were reported in the pelagic gillnet fishery for yellowfin tuna (*Thunnus albacares*), sharks and seerfish (*Scomberomorus commerson* and *S. guttatus*) (Yousuf et al*.,* 2009). Along Indian coast, 98.8% mammal mortality reported were due to entanglement/ incidental capture in gillnets (Jeyabaskaran et al*.,* 2016). During 1976-2013, 766 dolphin entanglements were reported from different states (Kerala, Karnataka, Tamil Nadu and Andhra Pradesh) of India, out of which 757 were due to gillnets (Jeyabaskaran et al*.,* 2016).

Koya et al. (2018) reported the co-occurrence of dolphins and turtles with tuna gillnet fishery, as about 0.12% of the total tuna catch consisted of dolphins and turtles, in the north-eastern Arabian Sea, off the north-west coast of India. This report was based on data from 567 fishing operations spread across six years (2011-2016). More dolphin interaction with gillnets occurred during summer months and the least during the post-monsoon months (Koya et al., 2018). Kumaran (2012) recorded entanglement of 14 cetacean species in gillnets. A preliminary study conducted at selected locations in Tamil Nadu, Kerala and Gujarat during 2015 found incidental catch of 1 to 10 dolphins per year per vessel (FAO, 2017). Dolphins, incidentally caught in the net, were generally reported as dead upon hauling (FAO, 2017; Koya et al., 2018). A recent study by Joseph et al. (2021) covering 20 harbours across India on cetacean interaction with gillnets, trawls and purse seines reported that cetacean interaction was maximum with gillnets (57.7%) and small mesh gillnets operated near-shore were more prone to cetacean interaction than large mesh gillnets operated in high seas.

Due to the large-scale gillnet operations in south east coast of India, the probability of accidental gillnetting of cetacean species of a greater diversity is high. Chilka lake in Odisha is home to about 158 Irrawaddy dolphins, *Orcaella brevirostris* which are listed as 'vulnerable' in the IUCN Red list of threatened species. Majority of reported Irrawaddy dolphin deaths were due to accidental capture and drowning in gillnets and drag nets (Khan et al., 2018).

Incidental catch of dugongs in gillnets is one of the major causes of dugong mortality according to a UNEP report (Marsh et al., 2002). In Indian waters, the dugong (*Dugong dugon*) population is facing a risk of local extinction due to high mortality in the wild (Marsh et al., 2002). Fishery-related factor such as entanglement in gillnets is one of the reasons responsible for dwindling dugong numbers in Gulf of Mannar and Palk bay region, other reasons being illegal hunting and boat strikes (Nair et al., 1975: Das & Dey, 1999; Marsh et al., 2002; Sivakumar & Nair, 2013). From Andaman Nicobar Islands, D'Souza et al. (2010) reported that the major reason for dugong mortality was entanglement in gillnets, as dugongs must surface for one or two seconds to breathe at frequent intervals (Anderson, 1981).

Marine turtle incidence

Fishing gear interaction *viz.,* either entanglement or ingestion of fishing gear or its fragments is a serious problem which has been affecting the marine turtles worldwide (Wilcox et al., 2018). The interaction of sea turtles with fishing gears had been reported from various parts of the world such as Malaysia (Chan et al., 1988), Tunisia (Gerosa & Casale, 1999), Trinidad and Tobago (Lum, 2006) and India (Vivekanandan, 2002). Marine turtle bycatch is a severe problem in many passive fishing gears including gillnets (Gilman et al., 2010). On the high seas, they get caught mostly in massive drift nets. In many ecosystems, turtle bycatch in gillnets is a major cause of their decline (Lewison & Crowder, 2007; Gilman et al., 2010). One possible reason could be that turtles caught in gillnets have higher mortality rate as they have lesser survival chances than those caught in trawls or longlines (Lewison & Crowder, 2007; Wallace et al., 2013). Peckham et al. (2007) estimated that up to 1000 loggerhead turtles are dying in gillnets annually in Mexico due to small scale gillnet fishing. Large-scale gillnetting also contributes to sea turtle mortality (Peckham et al., 2007; Alfaro-Shigueto et al., 2011).

Turtles entangling with nets die due to drowning (Wilcox et al., 2018). Since set gillnets are left in sea for periods extending from several hours to days, the entangled sea turtles cannot easily come to the surface for breathing and die by forced apnea (Casale, 2011). Coastal gillnet fishing can have indirect adverse impacts as well on turtles such as through capture in abandoned pieces of net (ghost net fishing) and interference with their feeding and nesting areas (Sacchi, 2021). ALDFG is recognized as a major debris item responsible for turtle entanglement (FAO, 2009). Turtles entangled in gillnets are released mostly live, but realistic estimates on post-release survival are limited (Chaloupka et al., 2004). Costs for tracking turtles released at sea, vulnerability to predators after release etc. make monitoring difficult (Swimmer et al., 2013).

Apart from entanglement, ingestion of the gear or gear parts is detrimental to marine turtles (Santos et al., 2015). In fact, sea turtles were one of the first taxonomic group reported to ingest plastic debris (Cornelius, 1975; Schuyler et al., 2014). But in many of the ingestion records, the origin of debris is not recorded or not distinguishable and hence the level of fishing gear ingestion by turtles is not well known. Fishing ropes, monofilament lines, nets and fishing hooks were reported as ingested by the green turtles in the eastern coast of Sharjah Emirate, UAE (Yaghmour et al., 2018). Among all the life stages of turtles, juveniles are the most vulnerable to lost gear interaction, probably due to feeding preferences (Nelms et al., 2016; Duncan et al., 2021).

Five species of sea turtles inhabit the Indian waters for feeding and breeding purposes, olive ridley (*Lepidochelys olivacea)*, the green turtle (*Chelonia mydas*), loggerhead turtle (*Caretta caretta)*, the hawksbill (*Eretmochelys imbricata)* and the leatherback (*Dermochelys coriacea)* (Rajagoplan, 1996). All these are protected species under the Indian Wild Life (Protection) Act 1972, Schedule I. Gillnets accounted for 76.8 and 60% of turtles incidentally caught along the Indian coast, during 1985-95 period and 1997-98 period, respectively (Rajagopalan et al., 1996 & 2006). Examples of records on turtle bycatch/ entanglements in gillnets from different locations of India are given in Table 2.

The threat to marine turtles by gillnets in India is more pronounced along the east coast, *viz.,* coasts of Odisha, West Bengal, Andhra Pradesh and Tamil Nadu compared to the west coast. About 60-70% of turtle mortality along east coast was due to incidental catch in gillnets (Hykle & Migraine, 2013). The Odisha coast is one of the four significant arribada beaches of the olive ridley sea turtle in the world having three mass nesting beaches (Gahirmatha, Devimuth and Rushikulya). Since the 1980s, the incidental catch of olive ridleys in gillnets and bottom trawls has been reported from Odisha (Kar, 1980). Recent studies by Behera et al. (2016) along the Gahirmatha coast of Odisha showed that mortality of turtles was mainly due to illegal fishing in the near shore waters using trawls and gillnets. An Empowered Committee 2003 (of Supreme Court of India) recommended banning of gillnet boats within 5 km of the three mass nesting beaches for 3 months. Besides, the Odisha Marine Fishing Regulation Act and Rules 1983 prohibits any kind of mechanised fishing within 5 km of the shore along Odisha coast.

The rising number and size of fishing units and improvement in technology has become the major reason for sea turtle mortality in Indian waters in recent years. Koya et al. (2018) estimated a maximum of three turtles as bycatch per operation of large mesh tuna gillnets based on their studies off north-west coast of India. The study observed 65 turtles in 56 operations with a catch rate of 0.11 turtle per operation and further that maximum turtle incidence occurred during post-monsoon season and less during summer season. A 2015 study among fishers from Tamil Nadu, Gujarat and Kerala operating tuna/seer drift gillnets reported 1 to 7 turtle (mostly green turtle and Olive ridley turtle) encounters during every fishing trip extending to a month (FAO, 2017). In both the studies (FAO, 2017; Koya et al., 2018) fishers reported that in majority of the cases, turtles entangled were live when landed and were cleared from the net and released back to the sea immediately. But the actual survival rate is uncertain due to absence of monitoring program. According to Parga et al. (2020) if the conditions allow, immediate releasing of the incidentally caught turtles back to the sea while they are active and alert, increases the chances for post-release survival. For developing an integrated and collaborative sea turtle conservation programme in India, a *UNEP/CMS-IOSEA* (United Nations Environment Programme / The Convention on Migratory Species (CMS) - The Indian Ocean's South-East Asia) project assessed various threats to sea turtle population along coastal states of India and identified fishing gear interaction as one of the major threats to turtles which included gillnet interactions also (Shankar & Andrews, 2006).

Control measures

Marine mammal and turtle interaction with gillnets is mostly harmful to these organisms. It also negatively affects the fishers by depredating on the catch and damaging the gear. Fishers need to spend more money for replacing the damaged gear besides loss in fishing time, reduction in catch and economic loss. For managing the impact of gillnets on mammals and turtles, spatial and temporal closures of fisheries have a greater role to play (Regular et al., 2013; FAO, 2021) and have been implemented in many places (Murray et al., 2000; Reeves, 2000). Awareness is to be created among fishers about the importance of conservation of these vulnerable species. Experienced fishers will be able to identify the location and season of occurrence of these animals and such areas can be avoided during fishing. Gear modifications and operation-based measures are recommended by researchers to avoid mammal (Hamilton & Baker 2019; FAO, 2021) and turtle interaction (FAO, 2019) with gillnets.

Control of mammal interaction: Increasing fishing effort has a direct influence on cetacean interaction with fishing gear. Reducing the number and size / capacity of vessels and volume of gear (length x height) deployed per operation would reduce incidental catch of mammals in gillnets to a certain

Table 2. Examples of recorded incidental catch of marine turtles in gillnets from Indian waters

Year	Turtle	Location	Reference
1983	Olive ridley, *Lepidochelys olivacea*	Gahirmatha, Odisha	Silas et al., 1983
1985-95	Green turtle, *Chelonia mydas,* Olive ridley, *Lepidochelys olivacea,* Loggerhead *Caretta caretta* and Hawksbill *Eretmochelys imbricata*	West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kamataka	Rajagopalan et al., 1996
1993-1994	Olive ridley, *Lepidochelys olivacea*	Odisha	Pandav et al., 1997
1993-1998	Olive ridley, *Lepidochelys olivacea*	Odisha	Pandav & Choudhury, 1999
1997, 1998, 1999	Olive ridley, (*Lepidochelys olivacea)* *Other species not specified*		Rajagopalan et al., 2001
1997-1998	Green turtle *Chelonia mydas,* Olive ridley, *Lepidochelys olivacea,* Loggerhead *Caretta caretta* and Hawksbill *Eretmochelys imbricata*	Odisha, Andhra Pradesh, Kerala, Tamil Nadu, Goa	Rajagopalan et al., 2002
2000-2001	Olive ridley, *Lepidochelys olivacea*	Nagapattinam, Tamil Nadu	Bhupathy & Karunakaran, 2003
2001-2002	Green turtle, *Chelonia mydas* and Hawksbill *Eretmochelys imbricata*	Agatti, Kavaratti and Minicoy of Lakshadweep islands	Tripathy et al., 2002
2000-2001	Olive ridley, *Lepidochelys olivacea*	Andhra Pradesh	Thripathy et al., 2003
2003-2005	Olive ridley, *Lepidochelys olivacea*	Chennai and Nagapattinam, Tamil Nadu coasts	Bhupathy, 2007
2011-16	Turtle (species not specified)	Veraval, Gujarat	Koya et al., 2018
2006	Green turtle *Chelonia mydas,* Olive ridley, *Lepidochelys olivacea*	Nagapttinam and Mamallapuram and Chennai in Tamil Nadu & North Kerala	Bhupathy & Saravanan, 2006
2010-2012	Green turtle *Chelonia mydas,* Olive ridley, *Lepidochelys olivacea* and Hawksbill *Eretmochelys imbricata*	Tamil Nadu	Saravanan et al., 2013a
2010-2012	Olive ridley, *Lepidochelys olivacea*	Andhra Pradesh	Saravanan et al., 2013b
2010-2012	Green turtle *Chelonia mydas,* Olive ridley, *Lepidochelys olivacea,* Hawksbill *Eretmochelys imbricata* and Leatherback, *Derrmchelys coriacea*	Karnataka	Ravi & Rakesh, 2013
2010-2012	Olive ridley, *Lepidochelys olivacea* and Green turtle, *Chelonia mydas*	Gujarat	Goswamy et al., 2013
2010-2012	Olive ridley, *Lepidochelys olivacea*	West Bengal	Bhadury et al., 2013
2013-2014	Olive ridley, *Lepidochelys olivacea*		Sachithanandam et al., 2015
2015	Turtles all species	Chennai harbour	Dharini & Shriram, 2015
2015	Green turtle *Chelonia mydas,* Olive ridley, *Lepidochelys olivacea*	Tamil Nadu, Kerala and Gujarat	FAO, 2017
2018	Turtles; species not specified	Veraval, Gujarat	Koya et al., 2018

extent. Technical modifications in gillnets such as acoustically reflective nets by incorporating reflective components (barium sulphate or metal compounds) into the nets can help cetaceans to detect gillnet and avoid becoming entangled (Larsen et al., 2007). These materials cause increase in acoustic reflectivity, net's visibility or twine stiffness (Trippel et al., 2003; Koschinski et al., 2006; Werner et al., 2006; Mooney et al., 2007; Bordino et al., 2013). However, along with reduction of cetacean interaction reduction in target catch limits its adoption by fishers (Mooney et al., 2007; Bordino et al., 2013). Acoustic pingers and alarms are used to reduce marine mammal bycatch in gillnets and other fishing gears (Koschinski et al., 2006; Werner et al., 2006). These devices enhance detection of fishing gear by cetaceans that echolocate for prey detection and other reasons. They create an alert or unappealing sound that causes cetaceans to avoid the sound source or associate it with an obstacle to avoid (FAO, 2021). Pingers are most commonly used to avoid the bycatch of small cetaceans in gillnets, particularly harbour porpoise (Brownell Jr. et al., 2019; FAO, 2021). The first study conducted in India during 2019-20 with coastal gillnets operated off Cochin using dolphin pinger (Fishtek Marine, 70 KHz) showed that gillnet units without pingers were 2.3 times more prone to dolphin attack than pinger assisted gillnet units (Joseph Rithin, Personal communication). Tie-downs in bottom-set or midwater driftnet gillnet fisheries will reduce bycatch of small cetaceans. These are lines that are shorter than the height of the fishing net, with terminal ends attached to the float line and lead line along the net, at equal horizontal distances. Tie-downs reduce the profile of gillnet and give vertically curved shape to the net. However, these lines may increase the chances of entanglement of other species such as turtles (FAO, 2021).

Other modifications such as increasing the visibility and stiffness of the net by using thicker yarns, colouring the net, lowering the net height, altering net hanging ratio and increasing the distance between the bridle are some possible solutions to avoid mammal interaction (FAO, 2021). Subsurface deployment of nets reduces the chances of cetacean bycatch in gillnets (Hembree & Harwood, 1987; Dayaratne & de Silva (1991). Use of coloured and luminescent ropes was found successful in increasing the visibility of buoy lines' and anchor lines' to whales at night or in the deep ocean in Cape Cod Bay (United States of America) (Kraus et al., 2014). Dolphins are able to detect small mesh than large mesh webbing and hence use of alternate panels of small mesh with large mesh would be helpful in alerting the dolphins about the presence of gillnets (Lal Mohan, 1991). Weak ropes in gillnets and weak gillnet webbing, may help entangled baleen whales to escape, thereby reducing mortality and serious injury (FAO, 2021). Attachment of weak links (including swivels) connecting the set gillnets to the marker buoy line, which would break under any pressure maintained for longer than the time required to haul in the gear also help the entangled animals to escape (Werner et al., 2006; Knowlton et al., 2016; FAO, 2018).

Reducing soaking time also reduces the risk of mammal bycatch in gillnets but it might also reduce target catch (Northridge et al., 2017). Time-area closures to limit gillnet fishing and to avoid marine mammal bycatch have been reported from Australia (AFMA, 2010; 2011), New Zealand (Slooten, 2013), Mexico (Rojas-Bracho & Reeves, 2013) and Europe (Salmi et al., 2000; Proelss et al., 2011) which among many other measures seem to be more successful.

***Control of turtle interaction*:** Incidental catch of turtle in gillnets can be reduced through reduction in gillnet profile (vertical height) and removal or reduction in length of anchored gillnet tie-downs (Gearhart & Eckert, 2007; Price & Salisbury, 2007; Eckert et al., 2008; Gilman et al., 2010). Decreasing the length of tie down or removing them causes reduction in amount of webbing which in turn reduces or eliminates the bag of slack webbing and decreases the chances of turtle entanglement (Gilman et al., 2010). Narrower (lower profile) net is an effective and economically viable solution for reducing interactions with turtles. This is due to the combined effect of the net being stiffer, thereby reducing the chances of turtle entanglement and the net being shorter reduces the proportion of the water column where fishing takes place which in turn lessens the likelihood of turtles encountering the fishing gear (FAO, 2009). Attachment of visual mitigation measures like shark shaped silhouettes, illuminating portions of the net using green light sticks and light emitting diode lamps had shown reduction in number of turtles caught in gillnets (Wang et al. 2009; Wang et al., 2013; Ortiz et al., 2016). Making the nets more visible especially, the upper portion by using thicker twine, attaching corks, colouring the net etc. will help to reduce turtle interactions (Melvin et al., 2001). Increasing net hanging ratio, using buoyless floatlines and/or reducing the number of floats (Price & Salisbury, 2007; Gilman et al., 2010) are few other measures demonstrated with different success rates. However, most of these measures except net illumination cannot be considered as very successful due to the associated reduction in target catch (Gilman et al., 2010).

Entanglement and subsequent mortality of turtles due to derelict and lost gillnets can be lessened using easily degrading materials (e.g. thinner twine diameter and weaker material) which reduce the floatation capacity of lost gillnet (Gilman et al., 2010). Reduction in floatation decreases the vertical profile of nets and allow larger organisms to break free of the gear and escape (Gilman et al., 2010). Carr et al. (1992) tested degradable plastic plates for attaching floats to the headrope of gillnet. Biodegradable gillnets made of polybutylene succinate (PBS) resin blended with polybutylene adipate-co-tere-phthalate (PBAT) resin have been widely studied (Bae et al., 2012).

One of the major concerns with gillnet fishing is the low likelihood of survival of turtles caught, due to the long immersion time of the gears. Several strategies have been suggested to improve the survival rate of turtles caught in nets and to facilitate their release such as setting the net in shallow waters or adjusting the ballast so that the turtles caught may reach the surface to breathe during net immersion (Gearhart, 2003). Reducing the soaking time as well as frequent patrolling of gear to release entangled turtles will help to improve chances of survival of turtles caught (Gearhart, 2003; Watson et al., 2005; Gilman et al., 2006).

Knowledge gap

Different aspects of gillnet interactions with mammals and turtles need further research. One major aspect which would help in addressing the problem effectively is distinguishing whether animal entanglement is with active gear or lost gear. The potential consequences of the entanglement and ingestion of gear and gear material, respectively, on animals at the population level is yet to be studied in detail (Stelfox et al., 2016). What characteristics of litter attract mammals and turtles towards it and what prompts young ones to ingest these particles are to be clearly understood. Besides, there is noticeable absence of data on turtle and mammal interaction with fishing gear from the Indian, Southern and Arctic Oceans (Stelfox et al., 2016). In India, there is a lack of information on the severity of this problem and there is no proper system to undertake regular documentation of mammal and turtle interaction with fishing gears (Thomas, 2010).

Conclusion

The increasing number of gillnet fishing units and the upward trend in length and vertical height of net deployed, are likely to invite more marine mammal and turtles interactions in the future. This warrants regular monitoring of this fishery with special reference to incidental catch of these organisms and possible mitigation measures. Most importantly, the uncontrolled expansion of gillnet fishing effort in terms of size and number of vessel and gear is to be urgently monitored and regulated. In the Indian context, gillnetting being a livelihood option of relatively poorer sections of the fishing community, strict control measures such as ban on its operation, use of pingers etc are not viable as the fishers may not be able to afford such interventions. Regulations brought in by Govt of Kerala, India in 2018 by amending the Marine Fishing Regulation Act & Rules incorporating the maximum allowable dimension of the gillnet for operation and the engine power of vessel are to be considered as an initiative to be followed by other regions of the country. Time-area closure with the active participation of fishers seem to be the most viable mitigation measure for reducing gillnet bycatch. Recording and reporting of incidental catch of these organisms in gillnets is to be strengthened to assess the severity of the issue and to work out suitable policies and measures for addressing it. Focussed research is necessary to develop mitigation strategies which require participation of different stakeholders.

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