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Using local informant data and boat-based surveys to improve knowledge on the status of the Ganges River dolphin (Platanista gangetica gangetica)

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Using local informant data and boat-based surveys to improve knowledge on the status of the Ganges River dolphin (*Platanista gangetica gangetica*)

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Abstract

Freshwater cetaceans are one of the most threatened groups of mammals on earth. Limited resources for monitoring and low power to detect trends hinder the development of effective conservation. Using the southern Bangladesh subpopulation of Ganges River dolphins (*Platanista gangetica gangetica*), previously thought to be a closed population, I investigate cost-effective boat-based methods for monitoring and estimating population size, and the value of local informant data for contributing to knowledge on the status of this poorly-known subpopulation.

Detectability must be accounted for during surveys to make inferences on species' trends. However, many surveys use methods that do not account for detectability, assuming such approaches to be cheaper. I demonstrate that a combined visual-acoustic survey is a robust and cost-effective approach for monitoring. Using data from multiple seasons and marine surveys, I show the population may not be closed. I develop correction factors to account for imperfect detectability during past visual-only surveys and use these to show there is no detectable long-term (1999-2012) change in the abundance of this subpopulation.

Local informant data are sometimes considered to have the potential to provide information of value to monitoring population trends. A comparison of the long-term and seasonal trends from boat-based surveys and those reported by fishers showed poor agreement. Memory-related biases are likely to have impacted informant recall. However, local informant data proved useful in identifying causal mechanisms underlying dolphin susceptibility to bycatch in gillnets, in particular river depth and net mesh size. Furthermore, local informant data provided a minimum estimate of annual mortality that is deemed unsustainable, but is based on a number of assumptions and potential biases that are discussed.

Combined visual-acoustic surveys and local informant data represent cost-effective tools for addressing some of the significant knowledge gaps on freshwater cetacean status, aiding the development of evidence-based conservation strategies.

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Acknowledgements

Interviews were often followed by tea and an opportunity to meet the family

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Chapter 1.Thesis Introduction

*The Ganges River dolphin (*Platanista gangetica gangetica*). Photo: Elisabeth Fahrni Mansur/ BCDP/ WCS*

1.1. Knowledge on species status

1.1.1. Why monitor the status of species?

Species extinction rates are currently predicted at 100 to 1,000 times the historical base rate (Lawton and May, 1995). Without efforts to conserve biodiversity, 30 to 50% of all species face extinction by mid-century (Thomas *et al*., 2004). However, resources available for conservation fall short of what is needed (Balmford *et al*., 2002). Given the global lack of resources available for conservation there has been significant effort in developing methods for prioritising regions and species most in need of conservation attention (e.g. Myers *et al*., 2000; Grenyer *et al*., 2006; Schipper *et al*., 2008; Collen *et al*., 2009; IUCN, 2014; Sea Around Us Project, 2014). Identification of priority areas for conservation attention (e.g. diversity hotspots, threat hotspots) requires knowledge on the distribution and status of species. Re-evaluating the status of species at varying time points can be used to improve the conservation decision-making process (Stem *et al*., 2005) by judging the impact of policies or interventions (Pullin and Knight, 2001; Yoccoz, Nichols and Boulinier, 2001;

Danielsen, Burgess and Balmford, 2005; Baillie *et al*., 2008; Jones *et al*., 2011; Nicholson *et al*., 2012; Sutherland *et al*., 2004).

1.1.2. How to monitor species status

An assessment of species status is made by evaluating information on species population size, population trends and threats against a set of well-defined criteria. A number of organisations have developed criteria against which to judge the status of a species (e.g. NatureServe Conservation Status, NatureServe, 2014; Red Data Book of Russia, Iliashenko and Iliashenko, 2000). However, the most comprehensive, objective and globally utilised criteria are those of the International Union for Conservation of Nature (IUCN) (IUCN Standards and Petitions Subcommittee, 2014; Mace *et al*., 2008) which have been used to assess the conservation status of 75,000 animal, plant and fungi species (IUCN, 2014).

A declining or increasing trend in the abundance of a species may indicate one of two processes: 1) there is a genuine change in the number of individuals, or 2) there has been a temporal change in detectability. To reliably estimate abundance and detect trends, detectability - and how it may vary with time and space - must be estimated and accounted for (Thompson *et al*., 2002). The need for robust monitoring tools has led to the development of a range of methods that account for detectability. Distance sampling and capture-recapture are two methods that can be used to estimate detection probabilities, and therefore abundance (Buckland *et al*., 1993; Manning and Goldberg, 2010); however, standardised monitoring methods can be technically, analytically and logistically demanding, making them prohibitively expensive for many developing countries (Aragones, Jefferson and Marsh, 1997; Yoccoz, Nichols and Boulinier, 2001).

Where expense and logistics prohibit the use of methods that account for detectability, a relative measure of abundance (e.g. counts of individuals, daily fish landings) may provide a more cost-effective tool for monitoring (Thompson, Gowan and White, 1998). Relative indices of abundance assume that the resultant count is related to absolute abundance and that this relationship remains constant (Thompson *et al*., 2002; Nichols, Thomas and Conn, 2009; Güthlin, Storch and Küchenhoff, 2014). Commonly used indices of abundance include: catch per unit effort (CPUE) for monitoring fish stocks; densities of animal tracks, and faecal counts (Lynch, Shertzer and Latour, 2012; Güthlin, Storch and Küchenhoff, 2014). However, recent studies have shown that the relationship between relative and absolute abundance rarely remains constant and can be affected by changes in sampling effort (e.g. Barlow *et al*., 2006), efficiency of gear for harvesting species (Lynch, Shertzer and Latour, 2012), group size (Smith *et al*., 2006), and sighting conditions (Hammond *et al*., 2002).

1.1.3. Data gaps in monitoring effort

Efforts to improve knowledge on the status of species has resulted in a 100% increase in the number of species assessed on the IUCN Red List in only ten years (IUCN, 2014); however, analyses of the IUCN Red List have highlighted a number of taxonomic and geographic biases in our knowledge on species status (Vié, Hilton-taylor and Stuart, 2008). In particular, knowledge on species status is biased towards large "charismatic" species, particularly vertebrates, and species in developed countries (Myers *et al*., 2000; Grenyer *et al*., 2006; Schipper *et al*., 2008). Monitoring is geographically biased towards high-income countries where resources are available to employ robust monitoring tools, despite the fact that low-income countries harbour a greater fraction of global biodiversity (Myers *et al*., 2000; James, Gaston and Balmford, 2001; Collen *et al*., 2008). However, existing standardised monitoring methods may be difficult to employ in countries where conservation resources are limited (Aragones, Jefferson and Marsh, 1997; Danielsen *et al*., 2003; Danielsen, Burgess and Balmford, 2005).

1.1.4. Addressing data gaps in monitoring effort

A global lack of resources for conservation and significant knowledge gaps on the status of species has prompted efforts to develop low-cost alternatives to standard ecological monitoring techniques (Aragones, Jefferson and Marsh, 1997; Stem *et al*., 2005; Danielsen, Burgess and Balmford, 2005). One relatively inexpensive approach that has received considerable interest is the use of interviews with local informants. Interviews can yield rapid ecological data over a wide geographic area in areas where these data would otherwise be difficult to obtain (Turvey *et al*., 2014; White *et al*., 2005; Anadón *et al*., 2009; Turvey *et al*., 2013). Ecological data collected during interviews is commonly divided into local knowledge (knowledge specific to an individual that may be gained through a person's own experiences and observations) and traditional knowledge (the cumulative body of knowledge and perceptions passed down between generations by cultural transmission; Berkes, Colding and Folke, 2000; Turvey *et al*., 2014). Interviews with local informants have been used to study species migration patterns (Mallory *et al*. 2003); land cover change (Chalmers and Fabricius, 2007); species composition and distribution (e.g. Meijaard *et al*., 2011; Turvey *et al*., 2007), perceptions of conservation (Sarker and Røskaft, 2011), and socio-economic impacts of conservation management (Rönnbäck *et al*., 2003).

Most studies employing interviews have focused on qualitative analyses; however, there has been recent interest in the utility of interviews for collecting quantitative estimates of varying ecological parameters such as harvest levels of natural resources (e.g. Jones *et al*., 2008;

Moller *et al*., 2004; Moore *et al*., 2010; Rist *et al*., 2010), relative and absolute estimates of abundance (e.g. Anadón *et al*., 2009), and population trends (e.g. Anadón *et al*., 2009; Turvey *et al*., 2013). However, interview data are often viewed sceptically given the lack of a standardised approach for handling the range of biases that can impact the accuracy of informant recall of past conditions (O'Donnell *et al*. 2010; Daw 2010; Moore *et al*. 2010). Previous attempts to validate local informant data have shown both good agreement (Jones *et al*., 2008; Rist *et al*., 2010; Anadón *et al*., 2009), and poor agreement (Daw, Robinson, & Graham, 2011; Gavin & Anderson, 2005; Lozano-Montes, Pitcher, & Haggan, 2008; Lunn & Dearden, 2006) when compared to independently-derived survey data. However, the paucity of studies validating local informant data means there is still insufficient information from which to establish the effect of methods for handling biases. Given the potential of interviews as a rapid, low-cost monitoring tool for conservation, there is a need for further studies validating the quality and accuracy of informant data (Jones *et al*., 2008).

1.2. Knowledge on the status of freshwater cetaceans

1.2.1. Introduction to freshwater cetaceans

Freshwater cetaceans are some of the most poorly known cetacean species, occupying some of the most densely populated river systems in the world. The lack of basic knowledge on the biology, population status and ecology of many species is an artefact of their distribution within developing countries where there are limited resources for monitoring. The term 'freshwater cetacean' collectively refers to both the facultative freshwater cetacean species (i.e. species that can occupy both freshwater and near-shore marine habitats; Smith and Jefferson, 2002: Yangtze Finless porpoise, *Neophocaena asiaeorientalis asiaeorientalis*; Irrawaddy dolphin, *Orcaella brevirostris*; Franciscana or La Plata dolphin, *Pontoporia blainvillei*) and the species of 'true' or obligate river dolphin (i.e. species only known from freshwater habitats: Amazon River Dolphin, *Inia geoffrensis*; Araguaia River Dolphin, *I. araguaiaensis*; South Asian River dolphin, *Platanista gangetica*; Yangtze River dolphin, *Lipotes vexillifer*). While there has been recent genetic and morphometric evidence to suggest that subspecies of the Amazon River dolphin (i.e. Bolivian River dolphin, *I. g. boliviensis*) and the South Asian River dolphin (i.e. Indus River dolphin, *P. g. minor*) may in fact be separate species, the data are not conclusive (Banguera-Hinestroza *et al*., 2002; Ruiz-García, Banguera and Cardenas, 2006; Braulik *et al*., 2014a).

1.2.2. Status of freshwater cetaceans

Freshwater cetaceans are one of the most threatened groups of mammals on earth (Reeves, Smith and Kasuya, 2000). In 2007, the Yangtze River dolphin was declared Critically Endangered, Possibly Extinct according to the IUCN Red List of Threatened Species Categories and Criteria (Smith *et al*., 2008) following a range-wide survey that failed to find any individuals (Turvey *et al*., 2007). In 2013, the Yangtze Finless Porpoise, a subspecies of the more widely distributed Vulnerable Narrow-ridged Finless Porpoise, was up-listed from Endangered to Critically Endangered following a predicted decline of 92.4% in the time period 1990 - 2040 (Wang *et al*., 2013). The remaining four assessed species of freshwater cetaceans are listed as Endangered (South Asian River dolphin, Smith and Braulik, 2008), Vulnerable (La Plata dolphin, Reeves *et al*., 2012; Irrawaddy dolphin, Reeves *et al*., 2008), and Data Deficient (Amazon River dolphin, Reeves *et al*., 2013), with the Araguaia River dolphin awaiting assessment following its recent description (Hrbek *et al*., 2014).

Population declines and localised extirpations in freshwater cetacean populations have been attributed to a range of threats including: pollution (Kannan *et al*., 1993, 2005; Alam and Sarker, 2012); intentional killing for their products (i.e. meat, oil and blubber) that are used for medicinal purposes (Pilleri, 1972; Alves and Rosa, 2008), to fatten cattle (Kreb *et al*., 2010) and as a bait for catching economically important species of catfish (Smith and Smith, 1998; Gómez-Salazár *et al*., 2012; Iriarte and Marmontel, 2013); persecution due to perceived competition for fish and damaging fishing nets (Loch, Marmontel and Simões-Lopes, 2009); accidental entanglement in fishing gear, principally gill nets (Choudhary *et al*., 2006; Mansur *et al*., 2008); population fragmentation due to dam construction (Smith, 1993; Smith *et al*., 1998; Ahmed, 2000; Beasley, 2007; Braulik *et al*., 2014b); boat strikes (Zhao *et al*., 2008; Turvey *et al*., 2013); and declining food sources (Beasley, 2007; Smith, Shore and Lopez, 2007). Identifying the principal extinction drivers affecting populations of freshwater cetacean species is complicated by the fact most species face multiple interacting threats, particularly Asian species that occur in regions with dense human populations. While threats acting on their own may pose little threat to a species, threats acting synergistically can significantly increase rates of decline (Brook, Sodhi and Bradshaw, 2008), emphasising the need for improved understanding of the range of threats impacting freshwater cetaceans.

1.2.3. Status of the Ganges River dolphin

The South Asian River dolphin is comprised of two subspecies: the Ganges River dolphin (*P. g. gangetica*) known from the river systems of Bangladesh, India, Nepal and possibly Bhutan

(Smith, Braulik and Sinha, 2012); and the Indus River dolphin, *P. g. minor* known only from Pakistan (Braulik, Smith and Chaudhry, 2012).

Historically, all river dolphin species were placed into the superfamily Platanistoidea given their superficially similar appearance (Simpson, 1945). However, genetic studies have demonstrated that these similarities represent evolutionary convergence of unrelated cetacean taxa that have colonised similar freshwater environmental conditions, and *Platanista* has now been separated taxonomically from other river dolphin species and placed in an ancient, once diverse lineage that represents one of the earliest divergences within the odontocete (toothed whale) clade around 30 million years ago (Nikaido *et al*., 2001). *Platanista* is therefore one of the most evolutionarily distinct cetacean species.

It is estimated that the global population size of Ganges River dolphins is between 1,200 to 1,800 individuals; however, considerable parts of this species' range have not yet been surveyed (e.g. Meghna River in Bangladesh and Indian Sundarbans; see Figure 1.1), and so the true global population estimate may be closer to 2,500 individuals (Smith, Braulik and Sinha, 2012). The current IUCN assessment of Endangered for the Ganges River dolphin is based upon observed declines in range extent and localised extirpations in India (e.g. Sinha, 2000; Sinha and Sharma, 2003) and Bangladesh (Kaptai Lake in southern Bangladesh, Smith *et al*., 2001; see Figure 1.1). While repeat quantitative estimates of abundance from parts of this species' range are suggestive of a downward trend, limited resources and a lack of robust survey methods mean that basic information on Ganges River dolphin status and trends is lacking across large parts of their range. Monitoring Ganges River dolphins has been undertaken for a number of decades, but an absence of robust methods and logistical challenges has meant that many surveys have employed direct count surveys (i.e. single observer-team visual surveys; Biswas and Boruah, 2000; Sinha and Sharma, 2003; Behera and Mohan, 2006; Khatri, Shah and Mishra, 2010; Alam and Sarker, 2012; Singh and Rao, 2012) that lack precision and represent a minimum population estimate only as they cannot account for animals unavailable for detection (i.e. availability bias, Smith and Reeves, 2000). In acknowledgement of the lack of robust methods for monitoring, the International Whaling Commission (IWC) sub-committee has recommended that appropriate methods be developed for monitoring freshwater cetacean populations (International Whaling Commission, 2001).

While evaluating the relative contribution of each threat to overall mortality is complex given the potential synergistic effects, fisheries-related mortality (both accidental and intentional) is considered one of the most significant threats to the Ganges River dolphin. Studies from both India and Bangladesh have identified high levels of both accidental and intentional

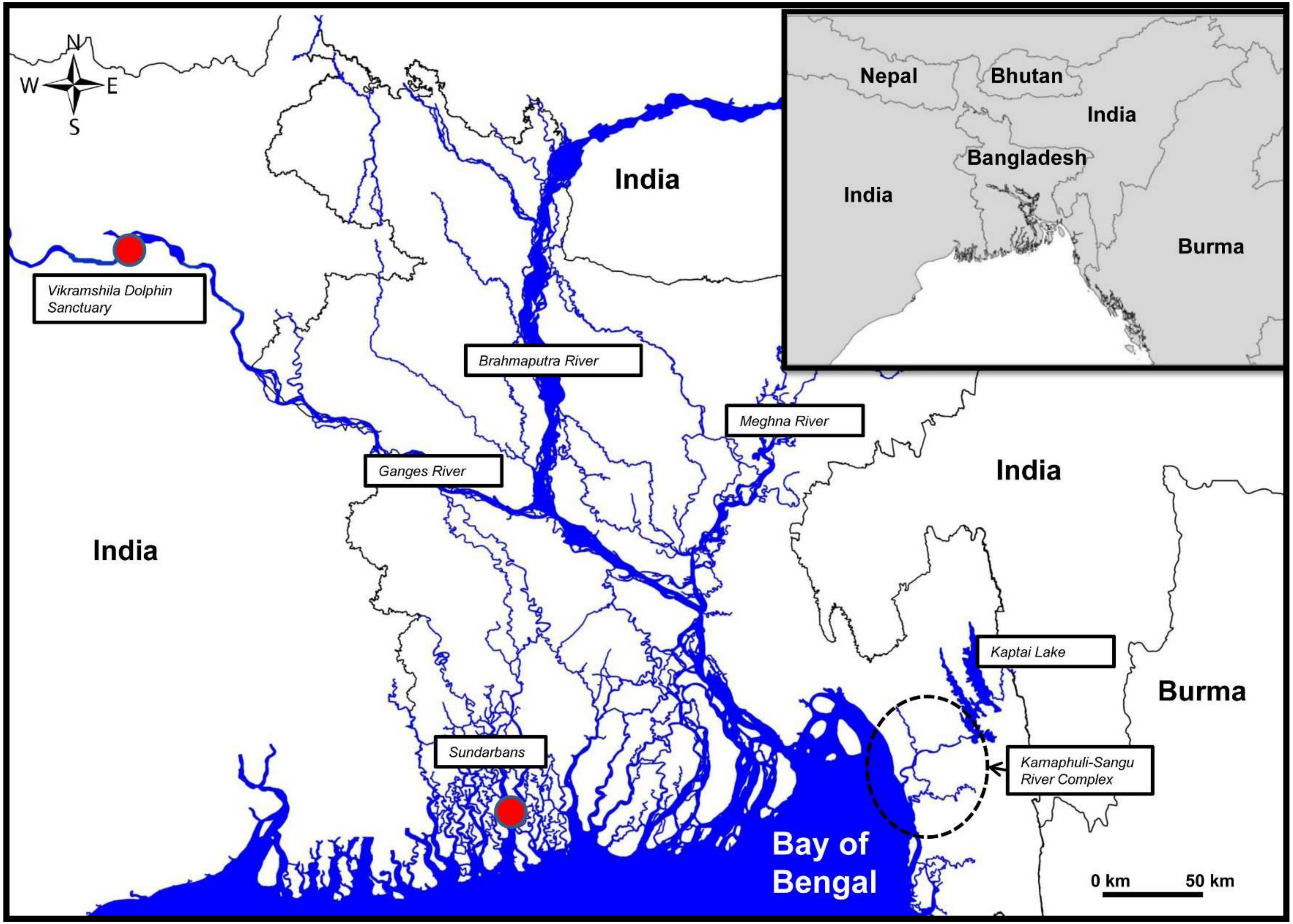

Figure 1.1: Map of the major rivers of Bangladesh. The red dots indicate the location of dolphin sanctuaries.

fisheries-related mortality (Choudhary *et al*., 2006; Mansur *et al*., 2008; Wakid, 2009; Kelkar *et al*., 2010). In the Indian part of the Brahmaputra River, where there are an estimated 264 individuals (Wakid and Braulik, 2009), 14 dolphin mortalities were recorded in 2004 – 2005, and 16 mortalities in 2008 (Wakid and Braulik, 2009) although these figures are considered to represent a significant underestimate due to limited monitoring effort (Wakid, 2009; Wakid and Braulik, 2009). While these figures raise serious concerns, it remains difficult to assess the sustainability of fisheries-related mortality for populations and species given a lack of data on numbers of mortalities and the connectivity between populations.

1.2.4. Conservation of Ganges River dolphins

The extinction of the Yangtze River dolphin was a catalyst for discussions on the conservation requirements for other surviving freshwater cetacean species. However, complex networks of interacting threats, and an incomplete understanding of the specific extinction drivers for many populations, have hindered efforts to develop targeted action plans for freshwater cetaceans. Furthermore, conservationists have been limited in their efforts to address specific threats, such as anthropogenic modification of the hydrological regime of river systems (i.e. dam, barrage and bridge construction) and pollution, given the logistical, political and economic challenges they pose. To date, most conservation effort for Ganges River dolphins has focused on addressing the impact of fisheries-related mortality (both targeted and accidental). Killing and trade of Ganges River dolphins is prohibited under Schedule I of the Indian Wildlife Protection Act (1972), the Bangladesh Wildlife Preservation Act (1973), the Nepal National Parks and Wildlife Conservation Act 2029 (1973) the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and the Convention on Migratory Species (CMS).

Efforts to mitigate fisheries-related mortality have focused on the establishment of protected areas at dolphin abundance hotspots (e.g. the Vikramshila Gangetic dolphin sanctuary in Bihar, India, Choudhary *et al*., 2006; and three dolphin sanctuaries in the Bangladesh Sundarbans mangrove forest, Smith *et al*., 2010). Furthermore, considerable efforts have been undertaken in India, Bangladesh and Nepal to enforce local laws and reduce intentional killing of dolphins through educational outreach programmes (Choudhary *et al*., 2006; WCS Bangladesh Cetacean Diversity Project, 2013).

1.2.5. Research needs for river dolphin conservation

While considerable effort has been invested into implementing conservation strategies for the Ganges River dolphin, there is no evidence to demonstrate the efficacy of these approaches (Sinha, Behera and Choudhary, 2010). Robust monitoring methods resulting in accurate assessments of population size, trends and distribution are therefore of great importance for management of this species (Reeves, Smith and Kasuya, 2000), but logistical and financial constraints prohibit the use of many methods commonly used for monitoring marine cetaceans, highlighting a need for new robust approaches for monitoring.

Furthermore, there are significant gaps in our knowledge of the nature of freshwater cetacean interactions with artisanal freshwater fisheries, despite it being recognised as a widespread problem facing all freshwater cetacean species. While there have been efforts to quantify minimum mortality levels, there has been only a single study examining the impact of harvest on the survivability of a freshwater cetacean population (i.e. Mintzer *et al*., 2013).

Knowledge of bycatch levels alone is insufficient to develop well-defined management goals for reducing impacts of fisheries interactions on freshwater cetaceans. Efficient and effective management strategies for mitigating bycatch of marine cetacean populations require detailed information on the timing and nature of bycatch events and the predictability of these events. While there have been frequent observations of freshwater cetacean bycatch in gill nets, there is little empirical information upon which to determine the frequency and timing of these events, or the relative risks to cetaceans posed by specific gears employed in different freshwater environments. The lack of information on the factors influencing freshwater cetacean bycatch in gill nets is in part a result of inadequate funding for observational studies (Reeves, McClellan and Werner, 2013), highlighting a need for low-cost, rapid approaches for monitoring bycatch.

1.3. Objectives

The aim of this thesis is to improve knowledge on the status of the Ganges River dolphin in southern Bangladesh using boat-based surveys and interviews with local informants. The study focuses on a subpopulation of Ganges River dolphins that occupy four waterways of southern Bangladesh; the Karnaphuli River, the Sangu River, the Halda River and the Shikalbaha-Chandkhali Canal, which are collectively referred to as the Karnaphuli-Sangu rivers complex (Figure 1.1). The subpopulation of Ganges River dolphins in the Karnaphuli-Sangu rivers complex is thought to be isolated from the Ganges-Meghna-Brahmaputra subpopulation, by a 75 km stretch of the Bay of Bengal. Since 1992, numerous boat-based direct count surveys have been undertaken in the Karnaphuli-Sangu rivers complex (Ahmed, 2000, 2004); however, the only range-wide survey of all known dolphin habitat was undertaken in 1999 using a standardised direct count resulting in a minimum abundance estimate of 125 individuals (Smith *et al*., 2001). Given the possible isolation of this subpopulation and its small size, there is an urgent need to re-evaluate the status of river dolphins within this river system.

In chapter two, I use a combined visual-acoustic survey to investigate the factors that affect visual detectability of Ganges River dolphins. I explore how detectability influences power to detect trends for both a combined visual-acoustic survey and a single observer-team visual survey, and the relative costs of four survey methods.

In chapter three, I produce an up-to-date abundance estimate for the Karnaphuli-Sangu rivers subpopulation of Ganges River dolphins. I use correction factors to correct historical survey visual counts for factors affecting detectability, and use these revised absolute estimates of abundance to look for evidence of seasonal differences (late autumn to winter) and long-term (1999 to 2012) abundance trends. I also present the results from coastal surveys in which I test the hypothesis that salinity in the Bay of Bengal is a barrier to river dolphin dispersal.

In chapter four, I investigate whether local informants can detect both long-term trends (i.e. 13 year time period) and seasonal differences (late autumn to winter) in the Karnaphuli-Sangu rivers complex subpopulation of Ganges River dolphins by comparing informant data to boat-based survey data carried out over the same time period. I also explore how informants infer trends in abundance, and discuss the likely biases influencing these inferences.

In chapter five, I use interviews with local informants to investigate the factors influencing bycatch of Ganges River dolphins in gill nets in the monsoon within the Karnaphuli-Sangu rivers complex. I use the interview data to calculate a minimum count of annual mortality and assess the sustainability of mortality using the Potential Biological Removal equation. I also use interviews to explore levels of compliance with existing fishery laws. These data are then used to make recommendations for the conservation of this subpopulation.

In chapter six I discuss the key findings of the research presented in this thesis, and how these findings might direct both future research and conservation efforts.

Chapter 2. To see or not to see: investigating detectability of Ganges River dolphins using a combined visual-acoustic survey.

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Two Ganges River dolphins surfacing near Mongla Port in the Bangladesh Sundarbans.

2.1. Abstract

Detection of animals during visual surveys is rarely perfect or constant, and failure to account for imperfect detectability affects the accuracy of abundance estimates. Freshwater cetaceans are among the most threatened group of mammals, and visual surveys are a commonly employed method for estimating population size despite concerns over imperfect and unquantified detectability. We used a combined visual-acoustic survey to estimate detectability of Ganges River dolphins (*Platanista gangetica gangetica*) in four waterways of southern Bangladesh. The combined visual-acoustic survey resulted in consistently higher detectability than a single observer-team visual survey, thereby improving power to detect trends. Visual detectability was particularly low for dolphins close to meanders where these habitat features temporarily block the view of the preceding river surface. This systematic bias in detectability during visual-only surveys may lead researchers to underestimate the

importance of heavily meandering river reaches. Although the benefits of acoustic surveys are increasingly recognised for marine cetaceans, they have not been widely used for monitoring abundance of freshwater cetaceans due to perceived costs and technical skill requirements. We show that acoustic surveys are in fact a relatively cost-effective approach for surveying freshwater cetaceans, once it is acknowledged that methods that do not account for imperfect detectability are of limited value for monitoring.

2.2. Introduction

Estimates of abundance, trends over time, and distribution are all important for conservation management of threatened species (Yoccoz, Nichols and Boulinier, 2001; Ferrier, 2002; Collen *et al*., 2009). Too reliably estimate population size or habitat use, detectability, and how it may vary with time and space, must be estimated and accounted for (Thompson *et al*., 2002). Freshwater cetaceans are one of the most threatened groups of mammals on earth (Reeves, Smith and Kasuya, 2000). Accurate assessment of population size, trends and distribution are therefore of great importance (Reeves, Smith and Kasuya, 2000). However, limited resources and a lack of robust survey methods mean that basic information on river dolphin status and trends is lacking across large parts of their ranges.

The use of methods typically used for monitoring marine cetaceans is largely precluded for freshwater cetaceans due to constraints arising from survey conditions in river systems, and from differences in freshwater cetacean morphology and surfacing behaviour (Smith and Reeves, 2000). Distance sampling using a visual line transect is commonly used to survey marine cetacean species including Sperm whales (*Physeter macrocephalus*) (Barlow and Taylor, 2005), Killer whales (*Orcinus orca*) (Williams and Thomas, 2009), and Vaquita (*Phocoena sinus*) (Barlow, Gerrodette and Silber, 1997). This method has been attempted with freshwater cetaceans, e.g. Ganges River dolphins (*Platanista gangetica gangetica*) (Bashir *et al*., 2010a), Yangtze Finless porpoises (*Neophocaena asiaeorientalis asiaeorientalis*) (Zhao *et al*., 2008), and Amazon River dolphins (*Inia geoffrensis*) (Vidal *et al*., 1997) (Table 2.1). However, bathymetrical constraints in river systems mean that survey vessels usually cannot follow transect lines that are distributed randomly with respect to the distribution of cetaceans, violating a key assumption of distance sampling (Buckland *et al*., 1993). Mark-recapture using photo-identification has also been used to estimate the abundance of some freshwater cetaceans, such as Irrawaddy dolphins (*Orcaella brevirostris*) (Ryan *et al*., 2011; Beasley *et al*., 2013). However, the exceptionally small dorsal fin (or lack of one altogether in finless porpoises) and rapid surfacing behaviour of other freshwater cetacean species limits the feasibility of photo-identification, making mark-recapture generally impractical (Smith and Reeves, 2000).

Surveys of freshwater cetaceans often rely on counts from a single observer-team (Biswas and Boruah, 2000; Sinha and Sharma, 2003; Behera and Mohan, 2006; Bashir *et al*., 2010b; Khatri, Shah and Mishra, 2010; Singh and Rao, 2012; Akbar, Mehal and Arshed, 2004) on a boat following the thalweg or deepest area of the river channel (Table 2.1). Estimates of abundance from single observer-team visual surveys reflect a minimum population size because an unknown number of animals remains undetected (Smith and Reeves, 2000). Detectability of cetaceans is affected by two sources of bias: availability and perception (Smith and Reeves, 2000). Because of high turbidity, cetaceans in rivers are typically only available for detection when at the water surface. Availability for detection is therefore determined by dive times (Smith and Reeves, 2000) and group size, with larger groups being more detectable than smaller groups (Smith *et al*., 2006). Even if a cetacean is available for detection at the water surface, it may still go undetected due to perception bias resulting from inattention, observer fatigue, visual barriers (e.g. ships, bridge pilings and channel meanders), distance from observers, and poor sighting conditions (Smith and Reeves, 2000). Independent observer teams, either on the same vessel (i.e. double observer-team visual surveys) (Smith *et al*., 2006) or on separate vessels following one another (i.e. tandem-vessel visual surveys) (Zhao *et al*., 2008; Braulik *et al*., 2012a), can be used to estimate detectability related to perception bias with closed capture-recapture models. However, many rivers are too shallow to accommodate a survey vessel large enough to accommodate independent teams, and tandem-vessel visual surveys can be problematic as it can be difficult to distinguish individual groups and therefore match detections made by the front and rear vessels, especially at higher densities (Braulik *et al*., 2012a). These methods also do not account for availability bias.

An alternative (or supplementary) approach to visual surveys is the use of passive acoustic survey methods which allow cetaceans to be detected underwater, thus increasing their detectability assuming the animals are vocalizing and within detection range (Barlow and Taylor, 2005; Akamatsu *et al*., 2008). Small cetaceans, especially species occurring in turbid freshwater environments, are particularly good candidates for acoustic detection because they must vocalise frequently for navigation due to the poor visibility and complexity of their environment (Smith and Reeves, 2012; Jensen *et al*., 2013).

Table 2.1: A summary of methods used for estimating abundance of freshwater cetaceans over the last twenty years.

Method	Species	Advantages	Disadvantages	Examples
Distance sampling with visual line transect	Ganges River dolphin, Yangtze Finless porpoise	1. Can account for imperfect detectability.	1. Difficult or impossible to meet the assumption that dolphin distribution is random relative to the transect line because: a) cannot place a random transect line as vessels are constrained to following a deep navigable channel or shipping lane; b) dolphin distribution is not random and may be confined to the same deep navigable channel as vessels, or clustered at river banks.	Vidal *et al*., 1997 Bashir *et al*., 2010b Zhao *et al*., 2008
Mark-recapture with photo-identification	Irrawaddy dolphin, Amazon River dolphin, Ganges River dolphin	1. Can account for imperfect detectability.	1. Difficult to match individuals for species with limited recognisable markings and short surfacing times. 2. Possible invalidation of the assumption of population closure between sampling periods, due to length of time required to obtain enough photographs in one sampling period. 3. Requires a good photographer and expensive equipment.	Gonzalez, 1994 Zhou *et al.,* 1998 Kreb, 2004 Ryan *et al*., 2011 Beasley *et al*., 2013 Sutaria & Marsh, 2011
Single observer-team visual survey	Ganges River dolphin, Yangtze Finless porpoise, Amazon River dolphin	1. Requires little training or expertise.	1. Cannot account for imperfect detectability.	Biswas and Boruah, 2000 Aliaga-Rossel, 2002 Sinha and Sharma, 2003 Akbar *et al.*, 2004 Martin and da Silva, 2004 Behera and Mohan, 2006 Khatri, Shah and Mishra, 2010 Singh and Rao, 2012
Double observer-team visual survey	Ganges River dolphin, Yangtze Finless porpoise, Irrawaddy dolphin, Amazon River dolphin	1. Can account for imperfect detectability.	1. Requires a vessel large enough to accommodate two independent teams. 2. Impossible in shallow rivers. 3. Extra cost associated with a larger survey vessel and extra team.	Smith *et al*., 2006
Tandem-vessel visual survey	Indus River dolphin	1. Can account for imperfect detectability.	1. Cost of an additional survey vessel.	Braulik *et al*., 2012b

Combined visual-acoustic survey	Yangtze Finless porpoise	1. Can account for imperfect detectability. 2. A double-observer platform is not needed and so the survey can be carried out in small boats. 3. The small boats needed can survey shallow rivers as well as larger rivers. 4. Acoustic surveys yield higher detection probabilities than visual methods, so can provide more precise estimates of abundance.	1. Requires expensive equipment. 2. Specialist expertise needed to analyse the data. 3. Acoustic detection range may be limited in environments with high levels of unwanted noise e.g. high density vessel traffic.	Akamatsu *et al*., 2008

Acoustic methods have been employed in a number of studies of Yangtze Finless porpoises and Ganges River dolphins looking at underwater behaviour (Sasaki-Yamamoto *et al*., 2012; Kojima *et al*., 2011), echolocation characteristics (Akamatsu, Wang and Wang, 2005; Akamatsu *et al*., 1998, 2007) and abundance estimation (Akamatsu *et al*., 2008, 2013; Kimura *et al*., 2010). However, despite their demonstrated efficacy at improving detectability of animals, uptake of acoustic surveys has been slow due to perceived costs and technical skill requirements (Li *et al*., 2010).

The Ganges River dolphin is listed as Endangered in the IUCN Red List of Threatened Species (Smith and Braulik, 2008). It is regarded as a high conservation priority due to the range and magnitude of threats it faces, and its unique evolutionary history as a relict lineage (Collen *et al*., 2011). Ganges River dolphins are in widespread decline across the South Asian subcontinent due to bycatch by fishers, intentional killing for meat and oil, habitat loss, and probably pollution and boat collisions (Motwani and Srivastava, 1961; Kannan *et al*., 1993, 1994; Smith *et al*., 1998, 2001). Identification of robust, cost-effective methods to assess population sizes and trends is therefore an important priority. We used a combined visual-acoustic survey to investigate the factors affecting visual detectability of Ganges River dolphins, and make recommendations for the design of future surveys of freshwater cetaceans. We explore how detectability affects power to detect trends in abundance, and the relative costs of different survey methods.

2.3. Methods

2.3.1. Study site

In January and February 2012, surveys were carried out in three interconnected rivers and one canal in southern Bangladesh (Chittagong district) (Figure 2.1). Surveys covered a 20 km section of the Halda River, a 45 km section of the Sangu River, and the entire Karnaphuli River (75 km) and Shikalbaha-Chandkhali Canal (29 km). The Karnaphuli River was divided into the Upper Karnaphuli (the 47 km river section upstream of Kalurghat Bridge) and Lower Karnaphuli (the 28 km river section downstream of Kalurghat Bridge including Chittagong Port) because of differences between the two sections: the Upper Karnaphuli runs through plantations (teak and tea), agricultural land and small settlements and has very low densities of vessel traffic, while the Lower Karnaphuli is considerably wider and the riverbanks are dominated by a ship-breaking yard, a naval port, and Chittagong city. Waterways varied in width from 35 to 2,300 m, with a mean of 607 m (SD=449). Mean water depth in the approximate thalweg ranged from 5.4 m (SD=5.2) in the Sangu, to 8.4 m (SD=4.4) in the Lower Karnaphuli.

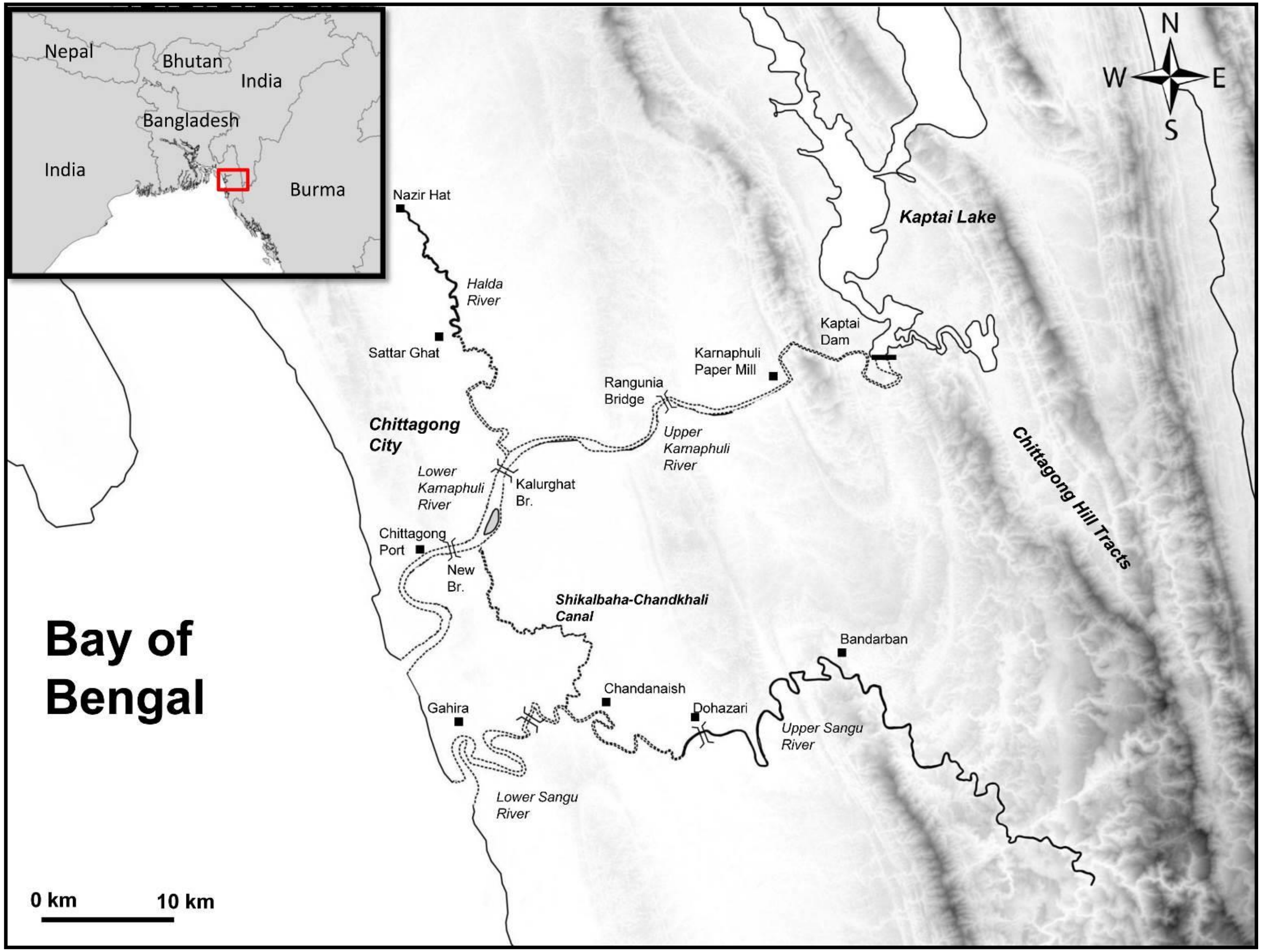

Figure 2.1: Map of the southern rivers of Bangladesh in Chittagong District (Upper and Lower Karnaphuli River, Halda River, Shikalbaha-Chandkhali Canal, Upper and Lower Sangu River). The inset map shows the location of the southern rivers (red box) within Bangladesh.

Due to shallow water depth, the survey vessel was regularly constrained to following the river thalweg. The research was carried out under a research permit issued to the lead author from the Ministry of Environment and Forest, Government of the People's Republic of Bangladesh.

2.3.2. *Pilot surveys*

In January 2012, two pilot surveys were carried out to identify dolphin distribution, and determine survey strip width based on the visual range of observers. Pilot surveys were carried out using the single observer-team visual method (i.e. the combined visual-acoustic method without simultaneous acoustic effort; see section 2.2.3 for details). Both surveys were carried out under excellent sighting conditions (Smith and Reeves, 2000). Waterways shallower than 50 cm in depth were excluded from the survey, as the pilot surveys and prior four months of field experience found no dolphins at depths this shallow. The pilot phase also included a study of dolphin dive time (see Smith and Reeves, 2000 for an outline of the method) based on six single animals and two groups of three animals.

2.3.3. *Visual and acoustic survey*

The combined visual-acoustic survey was carried out in February 2012, the low-water season, when sighting conditions are most favourable (Smith and Reeves, 2000). Surveys were carried out using a local motorised boat with a single observer-team during daylight hours. The observer-team consisted of a left, right, and central observer and a data recorder. All observers were trained to maximize consistency in distance estimation: observers were asked to estimate distance by eye using objects such as boats and bridge pilings, which were then compared to the distance measured by the lead observer using a global positioning system (GPS). Observers were positioned on the roof of the vessel at an eye height of 2.5-3.0 m above water level, and were rotated with two resting observers every 30 minutes to avoid fatigue (Smith and Reeves, 2000). Left and right observers searched from 90^{o} off the left and right beam to 10^{o} beyond the bow using Olympus 10x50 binoculars and the naked eye. The central observer used the naked eye to search a 20^{o} cone in front of the bow (10^{o} either side of the transect line).

Weather conditions (sun glare, wind, and rain/fog) and survey effort were recorded at 30 minute intervals, or whenever conditions changed, on a scale of 0-2 as described by (Smith *et al*., 2006). Scores were then summed to give a cumulative score on a scale of 0-6 (0 = excellent conditions, 6 = poor conditions). When a dolphin was sighted, the data recorder noted the latitude/longitude (using Garmin eTrex Summit HC Global Positioning System), estimates of distance and relative angle from the transect line to the sighting, time, vessel speed, group size as best/high/low estimates, and observer name. A group was defined as all individuals within 100 m of each other. All group size estimates were made in passing mode (i.e. survey vessel continues along the transect line) (Dawson *et al*., 2008).

A simultaneous acoustic survey from the same survey vessel was carried out using a towed hydrophone array system consisting of two stereo pulse event data loggers (A-tags: ML200-AS2, Marine Micro Technology, Saitama, Japan). Two data loggers were towed astern of the vessel on an 87 m long rope, with one positioned at 70 m and the other at 87 m. Each data logger consisted of two hydrophones separated by 19 cm (Figure 2.2). Hydrophone sensitivity of the data logger was set to -200dB/V at 130 kHz (100-160 kHz within -5dB band) which is close to the vocalisation frequency of the Ganges River dolphin (Pilleri *et al*., 1976; Herald *et al*., 1969).

To minimise the effect of availability bias, boat speed must be slow enough to allow dolphins to surface at least once within the visual range of observers, but fast enough to minimise the chance of a dolphin swimming past the boat twice (i.e. "double counting"). To estimate the visual range of observers we plotted a frequency distribution of the radial sighting distances of detections during pilot surveys of the Sangu, Halda and Upper Karnaphuli rivers. Sighting frequencies fell off rapidly beyond 200 m, and so this distance was used to define the visual range of observers. Mean dive time for the six single animals was 68 seconds (n=192 surfacings, 95% CI = 64-71) and 41 seconds for the two groups of three (n=245 surfacings, 95% CI = 38-44). We selected 10 km/hr as the boat speed for the survey; at this speed it would take 72 seconds for the boat to travel 200 m, allowing single animals to surface at least once within the visual range of observers. While mean estimates of dive time vary across studies (Smith *et al*., 2006; Wakid and Braulik, 2009; Sinha *et al*., 2010; Braulik *et al*., 2012a), observers typically have an unobstructed view of the river surface further than 200 m ahead of the vessel and so still have the opportunity to detect surfacings of longer diving animals. Dive time in Ganges River dolphins can be affected by activity type (e.g. feeding, resting, travelling) (Sinha *et al*., 2010) which is affected by time of day and tidal state (Gregory and Rowden, 2001). Surveys of each river were carried out at the same tidal state (flood tide and high tide slack) and time of day (8 am - noon), thereby controlling for dolphin activity as much as possible. In another recent survey of Ganges River dolphins (Smith *et al*., 2006), the authors assumed that at a mean boat speed of 10 km/hr availability bias was unlikely to significantly negatively affect visual detectability. To reduce perception bias, observers were rotated with off-duty observers, thereby minimising observer fatigue; we

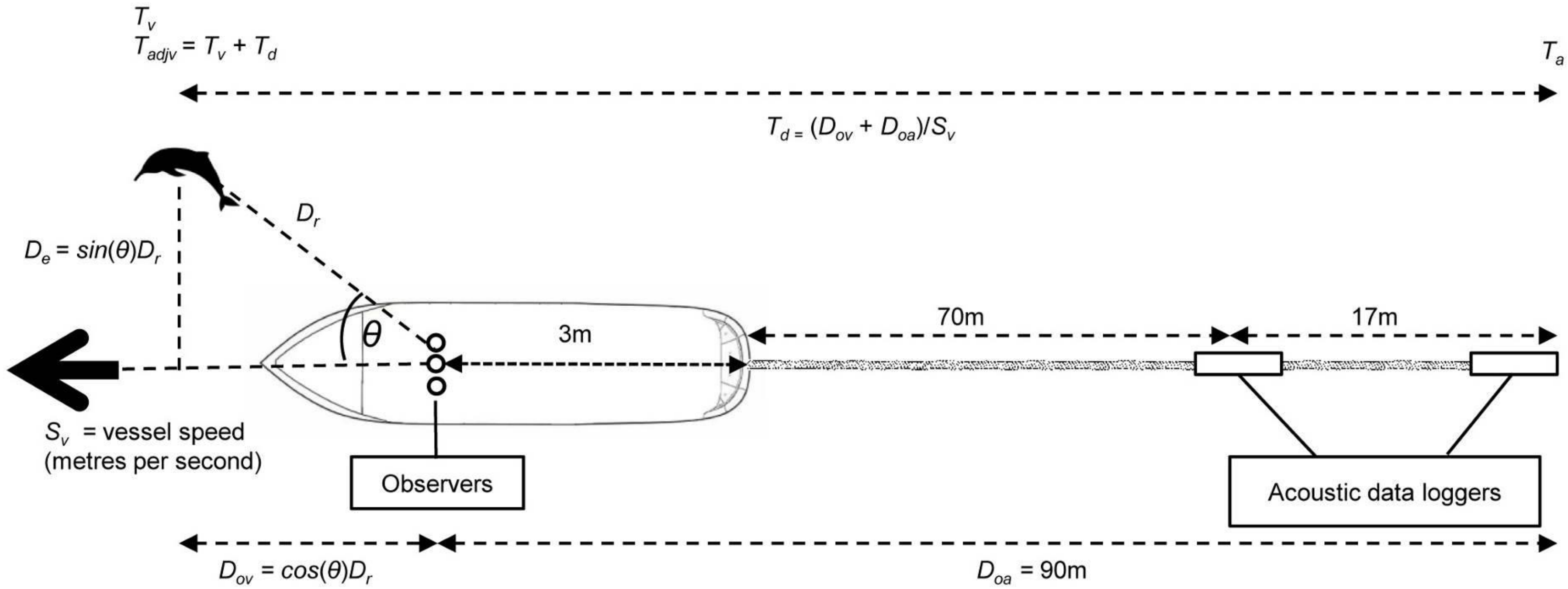

Figure 2.2: Schematic of the visual and acoustic survey set-up, with details of measurements taken for matching detections. Illustration of the visual and acoustic survey set-up, and measurements necessary for matching visual and acoustic detections including: time of visual detection (T_v), time of acoustic detection (T_a), time difference between time of visual detection and time of acoustic detection (T_d), radial distance of dolphin from observer (D_r), the angle between the forward line and the radial sighting distance line (θ), perpendicular sighting distance (D_e), adjusted visual time (T_{adjv}), forward distance between dolphin and observer (D_{ov}), vessel speed (S_v), and distance between furthest acoustic data logger and observer (D_{oa}).

surveyed a fixed strip width of 400 m (or less depending on channel width) based on a 200 m observer visual range either side of the transect line; and all surveys were carried out in very good to excellent sighting conditions with a cumulative score never exceeding 1. Acoustic detection range depends on the sound pressure level emitted by vocalising animals (Akamatsu *et al*., 2008). Dolphin detectability by acoustic data loggers is reduced with increasing distance, as sound pressure level from vocalising dolphins becomes lower than the detection threshold of the data loggers (Akamatsu *et al*., 2008). Acoustic detection of dolphins can also be negatively affected by high levels of background noise (e.g. from motorised vessels or snapping shrimp). An acoustic survey of Yangtze Finless porpoises using the same data loggers as used in this study calculated an effective acoustic detection distance of 300 m from the transect line (Akamatsu *et al*., 2008), beyond which acoustic detectability was found to decline significantly. As source levels from Ganges River dolphins and Yangtze Finless porpoises are comparable (Jensen *et al*., 2013), we assumed that the 200 m detection range either side of the transect line used for the visual survey would be sufficient for acoustic detection.

2.3.4. Calculating detectability

Detection probabilities were estimated using mark-recapture analysis, where visual observation is considered a mark and acoustic detection is considered a recapture. A Lincoln-Peterson estimator was used and detectability was calculated for each river. This approach is appropriate because the population was closed between samples and we assume that all individuals had an equal chance of being detected.

By re-arrangement of the Chapman-modified Lincoln-Petersen estimator, we calculated visual and acoustic survey detection probabilities ($\hat{P}$) and variance using the following equations:

$$\hat{P}_v = \frac{m}{n_a} \text{ and } \hat{P}_a = \frac{m}{n_v} \quad [2.1]$$

and variance (var) :

$$var(\hat{P}_a) = \hat{P}_v(1-\hat{P}_v)/n_a \quad [2.2]$$

and

$$var(\hat{P}_v) = \hat{P}_a(1-\hat{P}_a)/n_v \quad [2.3]$$

where n_v is the number of animals detected visually, n_a is the number of animals detected acoustically, and m is the number of matched detections. We constructed binomial 95% confidence limits using the 'binom' package in R (R Core Team, 2013).

2.3.5. Matching acoustic and visual detections

Ganges River dolphin vocalisations were visualized using an automated off-line software developed in Igor Pro 6.22A (WaveMetrics, Lake Oswego, OR, USA). Dolphin vocalisations form predictable patterns in inter-click interval and sound pressure level that can be differentiated from random background noise (Kimura *et al*., 2009). In environments where there is considerable background noise, estimation of acoustically detected individuals is problematic as it is difficult to distinguish dolphin click trains from noise. In addition, it is increasingly difficult to distinguish individual click trains from one another when animals are very close to one another. To determine the likelihood of overestimating or underestimating the number of acoustically detected individuals we examined the level of background noise to assess the potential for incorrect identification or missing of click trains. We also used the method described in Akamatsu *et al*. (2008) in which we compare acoustic and visual group sizes for matched detections, to look for evidence of underestimation of acoustically detected individuals.

Incorrect matching of visual and acoustic detections is potentially the greatest source of error in abundance estimation during combined visual-acoustic surveys (Evans and Hammond, 2004). Studies of marine cetaceans employing combined visual-acoustic surveys typically match visual and acoustic detections using the location of each at time of detection, and allowing for movement of individual animals based on knowledge of species movement patterns in response to survey vessels (e.g. Barlow and Taylor, 2005), however, little is known about the response of freshwater cetaceans to the presence of survey vessels. Akamatsu *et al*. (2013) proposed a multimodal detection model for matching visual and acoustic detections of Ganges River dolphins based on species dive time and time interval between vocalisations. While several published dive time estimates are available for this species (Smith *et al*., 2006; Sinha *et al*., 2010; Braulik, *et al*., 2012a; Wakid and Braulik, 2009), along with the data we collected during this study (see above), there is both considerable variation in estimates across studies and also wider uncertainty regarding the factors (e.g. ecological, behavioural) affecting dive time. Based on these concerns, we use a distance window for matching detections, similar to the time window approach described in (Akamatsu *et al*., 2008) which requires no assumptions on species dive time. We opted to use a distance window for matching detections rather than a time window, as time windows rely on the assumption that boat speed remains constant throughout the survey.

A key assumption of matching visual and acoustic detections is that animals are first detected by visual observers ahead of the vessel, and then by acoustic data loggers astern of the vessel. To ensure that dolphins could not swim in a stern-to-bow direction, boat speed should be faster than the swim speed of Ganges River dolphins. While no studies have investigated the maximum swim speed of this species, a recent study recorded individuals travelling at an average of 3.5 km/hr (Sasaki-Yamamoto *et al*., 2012), similar to that found for other freshwater cetaceans (Amazon River dolphin, typically <5.5 km/hr; Yangtze River dolphin (*Lipotes vexillifer*), 1.5-3 km/hr) (Weber *et al*., 2009; Sylvestre, 1985; Renjun *et al*., 1994). We validated this assumption by visualising the shape of the click train that indicates the direction in which dolphins passed the acoustic data logger (Figure 2.3). All click trains ran from a positive to negative angle in inter-click interval, indicating that animals passed the data loggers in a bow-to-stern direction. The time delay between when the sound source reaches the two hydrophones can be used to calculate the conical bearing angle to the sound source with a resolution of 271 ns (Akamatsu *et al*., 2005). The time at which a dolphin was detected was defined as the point when the signal arrival time between the two hydrophones was zero or closest to zero, indicating that the dolphin was closest to the data logger (Akamatsu *et al*., 2008). This method allows us to count the number of vocalising animals rather than the number of vocalisations.

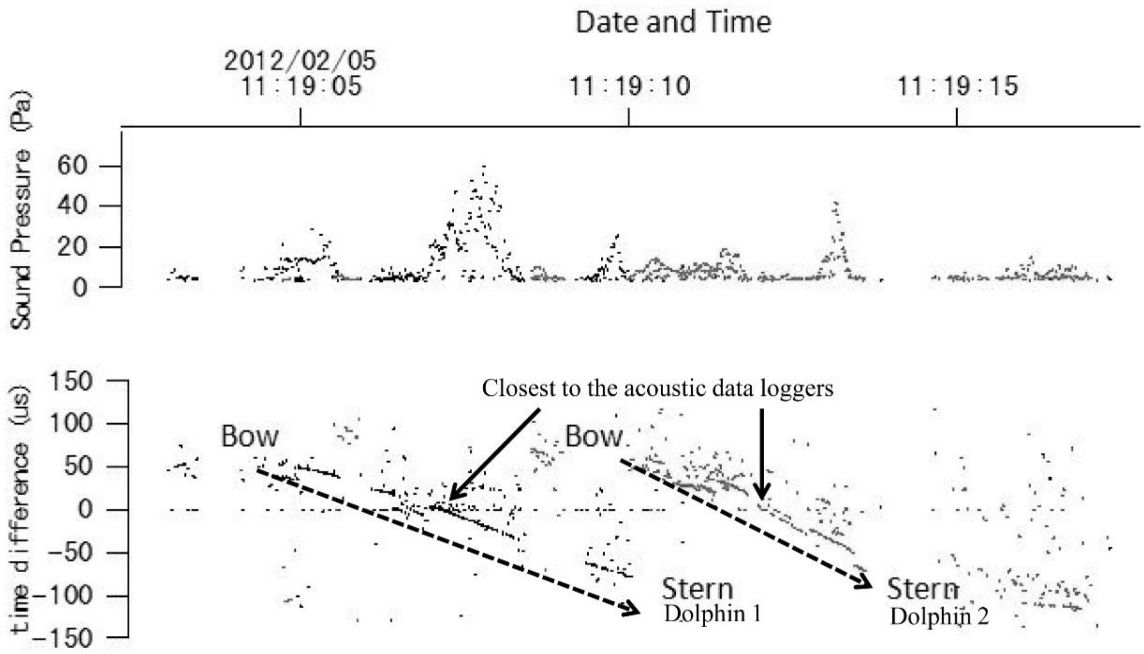

Figure 2.3: Patterns in sound pressure level and inter-click interval of Ganges River dolphin clicks. Trace of click trains from two Ganges River dolphins as they pass in a bow-to-stern direction illustrated using the time difference (μs) in inter-click interval (bottom image) and sound pressure level (top image).

Another fundamental assumption of closed population capture-recapture studies is that animals are not lost from the study area (i.e. 400 m survey strip) between visual and acoustic detection. If dolphins avoid or are attracted to survey vessels this may result in the loss or gain of animals between detection events. However, an independent study found no evidence of vessel avoidance or attraction in the closely related Indus River dolphin (*Platanista gangetica minor*) (Braulik *et al*., 2012a). In addition to which, only 9% of the length of all water ways exceeded the strip width and so there was little opportunity for animals to leave the study area.

We first accounted for the time difference T_d between visual and acoustic detections, given that visual detections are made ahead of the vessel and acoustic detections are made astern of the vessel (Figure 2.2). To calculate the time difference we calculated the forward distance between observers and the point of visual detection along the transect line D_{ov}, where θ represents the angle of the visual detection from the transect line and D_r is the radial distance of the animal from the observers. To obtain T_d we added D_{ov} to the distance between observers and acoustic data loggers D_{oa} and divided by the GPS recorded vessel speed at the time of visual detection S_v:

$$T_d = \frac{\cos\theta D_r + D_{oa}}{S_v} \qquad [2.4]$$

T_d was then added to the original time of visual detection T_v to give the adjusted time of visual detection T_{adjv}, which accounts for the time lag between visual and acoustic detection:

$$T_{adjv} = T_v + T_d \qquad [2.5]$$

If the dolphin did not move between visual and acoustic detection then the difference between T_{adjv} and acoustic detection time T_d is zero. However, if the dolphin swam towards the vessel then T_d is decreased and if it swam away from the vessel then T_d is increased, resulting in a negative or positive value between T_{adjv} and T_d. To match acoustic and visual detections, we applied a distance window to each T_{adjv}. The window ran in both a negative and positive direction to account for dolphins that swam either towards or away from observers between T_v and T_a. Only a single T_a could be matched to a single T_{adjv}; where more than one T_a fell within a distance window, the one closest to T_{adjv} was considered a match and the other was considered unmatched. However, where animals were detected in a group of two or more, only a single distance measurement was taken to the centre of the group. As groups were defined by all animals within 100 m of each other, any individual detected within a group was matched using the defined distance window plus an additional 100 m. To determine a distance window, we calculated the distance difference between T_{adjv} and the closest T_a. We plotted a cumulative frequency distribution of matched T_{adjv} and T_a at fifty metre intervals and selected a threshold distance by visual inspection of the frequency distribution.

2.3.6. Power to detect population trends

For a population to be considered Critically Endangered under IUCN criterion A, a minimum decline of 80% over three generation lengths has to occur. Assuming three generations is 60 years for the Ganges River dolphin (see Smith and Braulik (2008) for details) and a constant rate of decline, this is equivalent to an annual population decline of 2.65%. To illustrate differences in power between a single observer-team visual survey and a combined visual-acoustic survey, we estimated the number of repeat surveys required to detect change in a population declining at this rate over a 10 year interval (i.e. a 24% decline). Abundance ($\hat{N}$) and variance (var) for the 400 m survey strip detailed in this study were estimated using the Chapman-modified Lincoln Petersen estimator:

$$\hat{N} = \frac{(n_v + 1)(n_a + 1)}{m + 1} - 1 \qquad [2.6]$$

and

$$var(\hat{N}) = \frac{(n_v + 1)(n_a + 1)(n_v - m)(n_a - m)}{(m + 1)^2 (m + 2)} \qquad [2.7]$$

where n_v is the number of animals detected visually, n_a is the number of animals detected acoustically, and m is the number of matched detections.

The 400 m survey strip abundance estimate does not represent an overall estimate for the entire study area. Wide river width in the Lower Karnaphuli meant the channel had to be split into two strips that were surveyed simultaneously, one with a combined visual-acoustic survey and one with a single observer-team visual survey. An overall estimate of abundance for the subpopulation will require the development of correction factors to account for animals missed in sections where there was no acoustic effort.

The CV for the single observer-team visual survey was calculated using the mean and standard deviation of the two pilot visual surveys and the visual component of the combined visual-acoustic survey, and for the combined visual-acoustic survey using the CV of the 400 m survey strip abundance estimate. The probability of committing a Type 1 error (α) was set to 0.05, and the probability of making a type 2 error (β) was set to 0.2 so that power (1 - β) was 80%. All analyses were carried out in TRENDS version 3 (Gerrodette and Brandon, 2000).

2.3.7. Investigating factors affecting visual detection of river dolphins

We used a generalized linear model with a binomial error term and logit link function to model the effect of potential predictors on visual detectability of dolphins. The response was modelled as a binary factor where visual detections were either matched with an acoustic detection {1} or unmatched {0}. Predictor variables were observer experience (binary factor coded as: {0} inexperienced, i.e. having no prior cetacean survey experience, or {1} experienced, i.e. having carried out five or more prior surveys), and available observation distance (continuous factor), and the interaction. Ganges River dolphins are known to occur in higher concentrations at meanders (Sinha, 1997), but these features can temporarily block the view of the following river section. We modelled available observation distance as the distance between the meander and the dolphin when perpendicular to the survey vessel. Based on our mean estimates of dive time and a boat speed of 10 km/hr, dolphins located less than 200 m from a meander may never surface before the vessel passes by, therefore never becoming available for visual detection. Because ships can create sighting obstructions, we excluded data from the Lower Karnaphuli due to the high density of cargo ships in this region. Variables such as river width, sighting conditions, and observer effort were not included the model as they were controlled for in the survey design. Spearman's rank correlation was used to test for collinearity between variables.

We developed a global model containing available observation distance and observer experience. A candidate set of eight models was developed *a priori* and fitted in R 3.0.1 (R Core Team, 2013). Models were ranked according to Akaike's information criterion (AIC), and model selection was based on ΔAIC (the difference in AIC between each model and the model with the lowest AIC). Where there were models with ΔAIC < 2, model averaging was used to estimate coefficients as there was no clear support for a single model (Burnham and Anderson, 2002). We used the model-averaged results to predict visual detectability at available observation distances ranging from 0 to 2,100 metres.

2.3.8. Cost analysis

We compared set-up and daily costs for four survey methods (a single observer-team visual survey, a double observer-team visual survey, a tandem-vessel visual survey, and a combined visual-acoustic survey), and calculated the length of time required for each method to exceed a combined visual-acoustic survey in overall cost (i.e. sum of capital and daily running costs). Neither the tandem-vessel visual survey nor double observer-team visual survey were carried out during our field research, but costs for each of these two methods could be calculated from our own single observer-team visual survey. A number of costs were common to each method, but may have differed in quantity. The only cost exclusive to a particular method was the towed hydrophone array system necessary for the acoustic survey. All staff, boat, food and water, and printing costs were based on local Bangladeshi rates but presented in 2013 US dollars using an exchange rate of 1 USD = 79.8 Bangladeshi Taka (XE, 2013). Data analysis costs were excluded from the cost analysis due to the lack of data on the time required to learn how to analyse visual-only survey data and acoustic data and the inherent variability in existing local expertise. For example, the time required to analyse acoustic data from the combined visual-acoustic survey of the Karnaphuli-Sangu rivers complex was greatly reduced by collaborating with an acoustic expert. The impact of excluding this cost from the analysis will be discussed.

2.4. Results

2.4.1. Visual and acoustic detections

During each of the pilot single observer-team visual surveys a total of 124 and 109 animals were visually detected. We obtained a total of 114 visual detections and 159 acoustic detections during the combined visual-acoustic survey. Ninety five percent of visual detections from the combined visual-acoustic survey were within 100 m perpendicular distance of the transect line, and 100% were within 200 m. Unfortunately due to failure of an acoustic data logger, acoustic distance information was only available for the first two days of the survey (Halda, Lower Karnaphuli and Sangu rivers). However, of the acoustic detections with distance information, 99% were within 200 m perpendicular distance of the transect line (Figure 2.4). We visually detected 64 single animals, ten groups of two, seven groups of three, one group of four and one group of five.

2.4.2. Matching detections

Based on levels of background noise and the comparison of acoustic and visual group sizes, we conclude that our count of acoustic individuals from click train patterns is accurate. There was very little background noise (especially from major broadband sources such as snapping shrimp), and so it is unlikely that the number of click trains was overestimated or underestimated. The comparison of group sizes for matched detections also suggests that the number of acoustically detected individuals was not underestimated. In 74% of cases, numbers of visual and acoustic detections for each matched distance window were equal in size. Of the 26% of matches where the number of detections differed, in most cases (78%) the number of acoustic detections was higher than the number of visual.

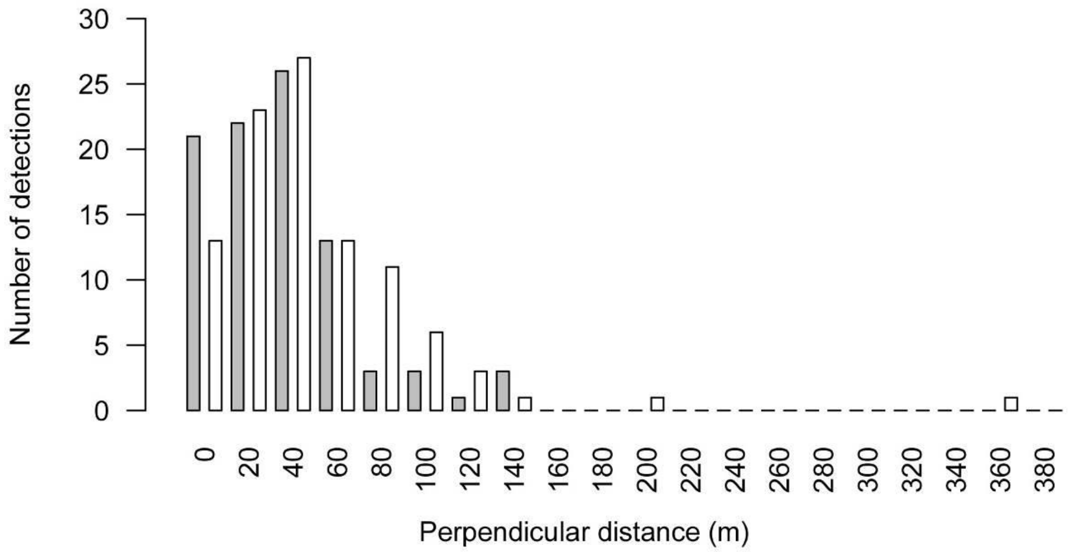

Figure 2.4: Frequency distribution of acoustic (white bars) and visual (grey bars) detections over distance from the transect line (perpendicular distance). Note that these data were only available for the Karnaphuli, Halda and Sangu rivers due to failure of one of the data loggers on day three.

Matches were largely unambiguous as the majority of visual (56%) and acoustic detections (64%) were of single animals, and 90% of all visual detections were separated by distances that exceeded the distance threshold (i.e. 349 m) required for matching individuals. There were 102 possible matches, of which 65% occurred within 100 m of each other and 90% occurred within 200 m of each other (Figure 2.5), supporting our assumption that animals moved relatively small distances between visual and acoustic detection. Based on visual inspection of the frequency distribution of number of visual and acoustic matches over distance, we selected a minimum distance threshold of 249 m for matching individuals. For groups of two or more individuals, we allowed for movement of up to 349 m as group distance measurements were based on a central point between individuals of the group and individuals could be separated by up to 100 m. Of the 102 possible matches, 89 fell within these distance thresholds, leaving a total of 70 unmatched acoustic detections and 25 unmatched visual detections. Of the unmatched visual detections, 20 were located in the Lower Karnaphuli and Sangu rivers.

Visual detection of dolphins at considerable distances ahead of the survey vessel can increase the distance threshold required for matching, as a longer time frame between visual and acoustic detection means that dolphins have more time to move. However, 85% of visual detections were made within a 300 m forward distance along the transect line. Based on a mean boat speed of 9.1 km/hr and an estimated dolphin swimming speed of 5.5 km/hr, dolphins could have moved up to 358 m between visual and acoustic detection; our detection thresholds more than account for this potential movement.

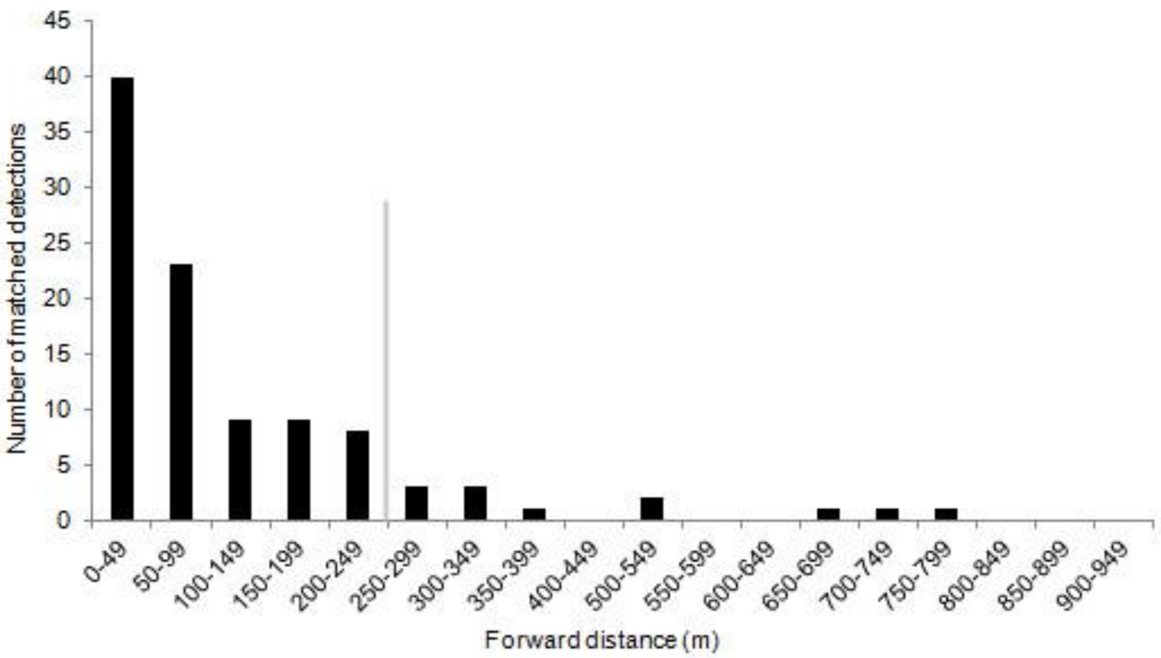

Figure 2.5: Distribution of forward distances between potential matched visual and acoustic detections. Frequency of numbers of matched visual and acoustic detections at 50m distance increments. The vertical grey bar indicates the cut-off point (249 metres) used to match visual and acoustic detections for single animals.

2.4.3. Detection probabilities

Acoustic detectability was consistently higher than visual detectability (Figure 2.6) with notable differences in estimates in the Halda and Shikalbaha-Chandkhali Canal (visual detection probability = 0.58 (95% CI: 0.44 - 0.72); acoustic detection probability = 0.89 (95% CI: 0.77 - 0.96)). Both acoustic and visual detectability were lower in the Lower Karnaphuli River (visual detection probability = 0.53 (95% CI: 0.42 - 0.65); acoustic detection probability = 0.71 (95% CI: 0.59 - 0.80)) than in the Halda River, Shikalbaha-Chandkhali Canal and Sangu River (visual detection probability = 0.59 (95% CI: 0.49 - 0.69); acoustic detection probability = 0.82 (95% CI: 0.72 - 0.89)), but overall there was little difference in estimates between the rivers. In the Upper Karnaphuli River, four individuals detected acoustically were not detected visually. Overall visual and acoustic detection probabilities were 0.56 (95% CI = 0.49 - 0.63) and 0.78 (95% CI = 0.72 - 0.83), respectively.

2.4.4. Surveys required to detect trends

The single observer-team visual surveys resulted in a lower survey strip abundance estimate with greater coefficient of variation (mean 116: CV=7%) than the combined visual-acoustic method (203: CV=3%). If the subpopulation of 203 animals were to experience a decline of 24% over a ten year period, five survey repeats would be needed to detect a decline using the combined visual-acoustic method compared to eleven survey repeats using the single observer method.

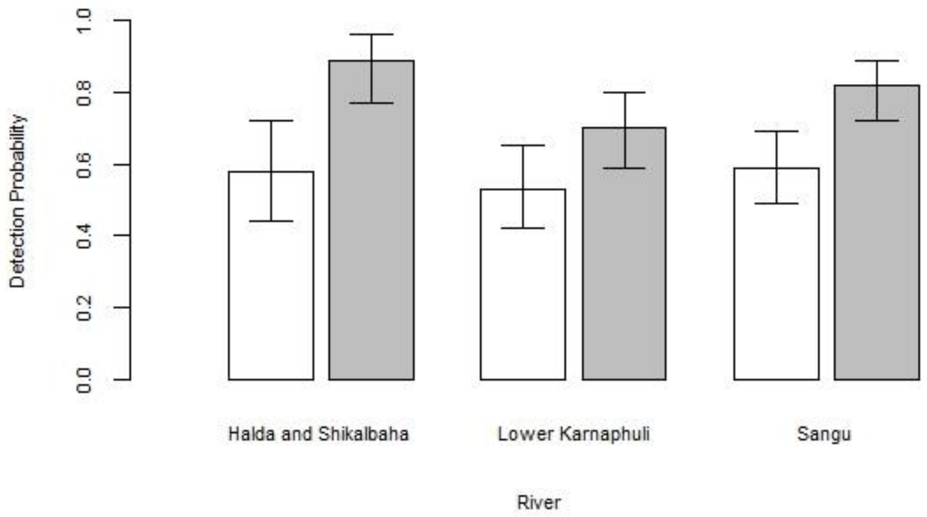

Figure 2.6: Detection probabilities and 95% confidence intervals for visual (white) and acoustic (light grey) methods.

2.4.5. Factors affecting detection by observers

There was no evidence of collinearity between any of the factors, and there was no strong support for a particular model as the top two models had ΔAIC ≤ 2 (Table 2.2). Standardised coefficients (*β*) are averages of *β* across the top two models, weighted by each model´s AIC weight. While there was no significant effect of observer experience on visual detectability of dolphins, there was a slightly lower probability of visual detection by experienced observers (β = -1.011, z = -0.552, p = 0.077) relative to inexperienced observers (β = -0.138, z = -0.299, p = 0.765). There was however a significant effect of available observation distance (β = 0.0023, z = 3.712, p = 0.000206) on visual detectability. While there is considerable uncertainty in predicted values of visual detectability at available observation distances ≤ 500 m (Figure 2.7), visual detection probabilities were less than 0.5.

Table 2.2: Summary of models used to explore factors affecting visual detectability.

Available Observation Distance	Observer Experience	Interaction	Number of parameters	AIC	ΔAIC	Akaike weight
Y	-	-	2	148.1	0	0.586
Y	Y	-	3	149.5	1.4	0.289
Y	Y	Y	4	151.2	3.1	0.122
-	Y	-	2	159.5	11.4	0.002

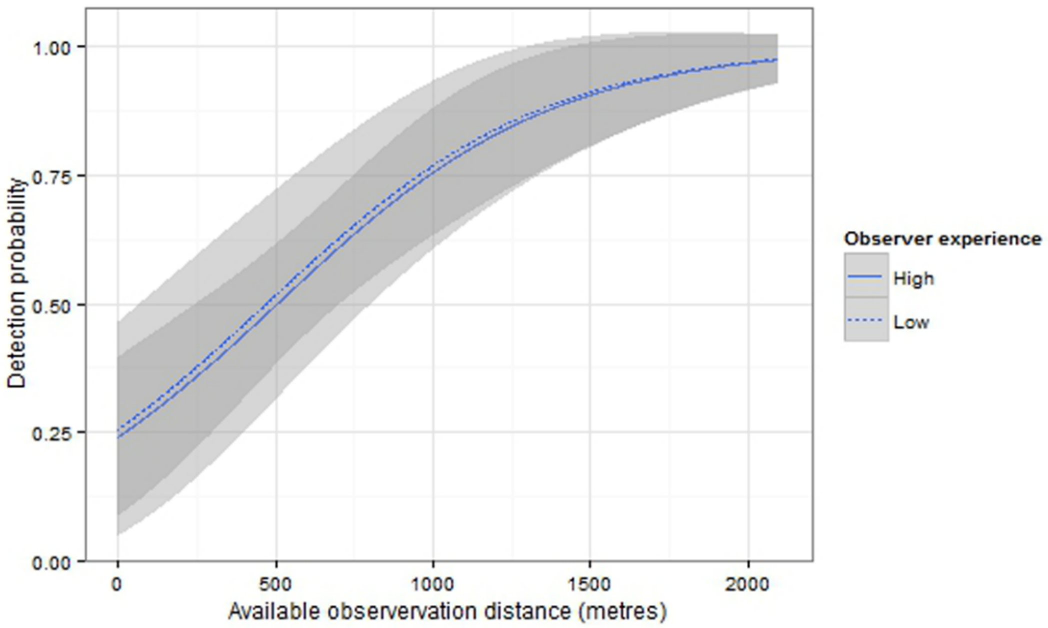

Figure 2.7: Predicted visual detectability and 95% confidence band, using model-averaged coefficients from candidate models.

2.4.6. Cost analysis of methods

Capital cost was highest for the combined visual-acoustic survey ($8,460) due to the cost of the hydrophone array ($8,000) (Table 2.3). However, because of higher daily running costs, the tandem-vessel visual survey and double observer-team visual surveys exceeded the combined visual-acoustic survey in overall cost after 40 and 56 survey days respectively (Figure 2.8). The single observer-team visual survey always remained the cheaper survey option as daily running costs were equivalent to the combined visual-acoustic survey.

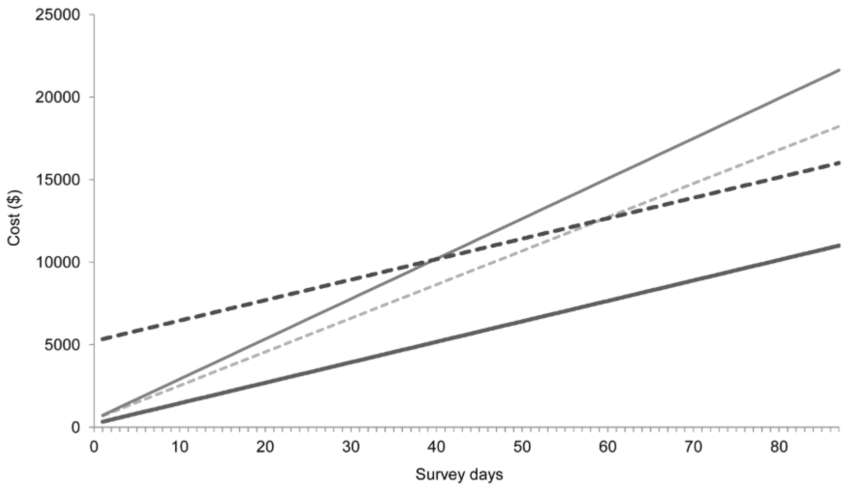

Figure 2.8: Overall cost of a single observer-team (thick black line), double observer-team (grey dotted line), tandem-vessel (thin black line) and combined visual-acoustic survey (thick dashed line) over number of survey days.

2.5. Discussion

The importance of accounting for imperfect detectability during wildlife surveys is widely recognised (Kéry *et al*., 2009) but methods that fail to account for it remain in use for a range of taxa (Keane *et al*., 2012; Thompson *et al*., 2002). Attempts have been made to account for imperfect detection during visual surveys of freshwater cetaceans by using double observer-team visual surveys [e.g. Smith *et al*. 2006] or tandem-vessel visual surveys [e.g. Braulik *et al*. 2012], but given that these methods are often impractical and do not account for availability bias, new approaches are needed. In this study we use a novel method for surveying Ganges River dolphins that accounts for imperfect detectability. Our results show that acoustic detectability is consistently greater than visual detectability because animals can be detected when submerged (Barlow and Taylor, 2005; Akamatsu *et al*., 2008), thereby reducing availability bias which can be a significant problem for visual surveys of diving animals.

2.5.1. Visual availability bias

Evaluations of availability bias for visual surveys of diving animals are typically undertaken by calculating the species dive-time and the number of potential surfacings within the visual range of observers for a given boat speed (Smith *et al*., 2006; Braulik *et al*., 2012a). Mean estimates of dive time for Ganges River dolphins are typically in the range of 70-115 seconds (Braulik et al., 2012a; Sinha et al., 2010; Wakid and Braulik, 2009). While dive-times of 465 and 504 seconds have also been recorded (Sinha *et al*., 2010; Bashir *et al*., 2013) these represent extreme estimates relative to existing studies. While there are a,

Table 2.3: A comparison of costs for four survey methods.

	Single observer-team visual survey			Double observer-team visual survey			Tandem-vessel visual survey			Combined visual-acoustic survey		
Item	Quantity	Capital	Daily Cost	Quantity	Capital	Daily Cost	Quantity	Capital	Daily Cost	Quantity	Capital	Daily Cost
Boat	1	-	$122	1	-	$200	2	-	$244	1	-	$122
Staff	5	-	$40	10	-	$80	10	-	$80	5	-	$40
Food and Water	5	-	$15	10	-	$30	10	-	$30	5	-	$15
Stationary	1	-	$8	1	-	$8	1	-	$8	1	-	$8
GPS	1	$110	-	2	$200	-	2	$220	-	2	$220	-
Binoculars	3	$240	-	6	$480	-	6	$480	-	3	$240	-
Hydrophone Array	-	-	-	-	-	-	-	-	-	1	$8000	-
Total	**-**	**$350**	**$185**		**$700**	**$318**	**-**	**$700**	**$362**		**$8460**	**$185**

number of factors that can affect cetacean dive-time, such as presence of vessel traffic (Li *et al*., 2008; Bashir *et al*. 2013) and time of day (Scott *et al*., 2001), little is known on the factors that influence dive-time in Ganges River dolphins. Without an understanding of the factors that influence dive-time and how these differ between surveys, studies that assume constant dive-times across surveys may underestimate the impact of availability bias on detectability resulting in biased estimates of abundance. While dolphins may have been unavailable for visual detection during this study, it is unlikely that availability bias constituted a significant source of bias as dolphins unavailable for visual detection could still be detected acoustically.

2.5.2. Perception bias

Visual barriers (e.g. meanders) may reduce the detectability of freshwater cetaceans, and such spatial variability in detectability may impact conclusions on habitat use (Mackenzie and Royle, 2005). Evidently in wide river systems (such as the main channels of the Sundarbans, Ganges and Brahmaputra) the negative effect of meanders on detectability would be minor as meanders would not significantly affect available observation distance. However, in narrow river channels, observation distance decreases substantially around a meander, thereby reducing the time available to view the following river surface and detect a potential surfacing. Our model shows that where available observation distance is less than 500 m, mean visual detection probabilities were less than 0.50. With a visual range of 500 m, dolphins might surface only twice based on our mean estimates of dive time and a vessel speed of 10 km/hr. The use of a rear-facing observer or reducing boat speed around meanders may help overcome this bias, although reductions in boat speed may not be practical in high-velocity rivers. Without modifications to survey design, visual-only surveys may significantly underestimate abundance in narrow, highly-meandering water ways, and therefore underestimate the importance of meanders as habitat for dolphins.

Studies have found that sighting rates of marine cetaceans differ significantly between experienced and inexperienced observers (Barlow *et al*., 2006). Increased observer experience is possibly associated with greater consistency in scanning behaviour when using binoculars (Secchi *et al*., 2001), and particularly improved detection in adverse conditions. We did not find an effect of observer experience on detection probability which may be due to the excellent sighting conditions throughout the survey, thereby lessening any effect of observer experience on dolphin detectability. Furthermore, narrow river width meant that there was considerably less area for each observer to scan compared to observation in wide river systems or marine environments. A smaller area to scan may lessen the importance of effective search behaviour, as a greater proportion of the river surface is within the field of view.

2.5.3. Trend detection

Failure to explicitly account for biases (Thompson *et al*., 2002) and low population density (Taylor and Gerrodette, 1993) can affect the ability to detect trends (Katsanevakis *et al*., 2012). As a population declines, the minimum detectable rate of change tends to increase (Taylor and Gerrodette, 1993). Notably, a study on the Vaquita, a highly threatened marine porpoise, showed that for a population size of 300, the minimum detectable annual rate of decline after ten annual distance sampling surveys was 18% (Taylor and Gerrodette, 1993). Identification of methods that are able to detect declines quickly and with minimal effort is particularly important for Ganges River dolphins. While the global population may number in the thousands, the range of this species has been severely fragmented by the construction of dams (Smith and Braulik, 2008), resulting in small isolated subpopulations (Smith and Reeves, 2000). Unless surveys can detect trends quickly, these subpopulations may fall below the minimum viable population size before a decline is detected. Under a ten year monitoring scheme, the combined visual-acoustic survey reduced the effort required to detect a rate of decline necessary for an IUCN listing of Critically Endangered under Criterion A. However, given the likely small size of many Ganges River dolphin subpopulations, we recommend that the goal of monitoring should be to detect declines in the shortest time frame possible to minimise the overall loss of individuals.

2.5.4. Costs of survey methods

While acoustic surveys can reduce effort in terms of the number of repeat surveys required for trend detection, the capital costs of a hydrophone array and associated technical expertise remain a barrier to their wide-scale adoption in cetacean monitoring programmes. Limited resources encourage the use of low-cost, familiar methods for monitoring; however, unless detectability is accounted for this may prove a false economy if the goal is to detect trends (McConville *et al*., 2009). Our results demonstrate that single observer-team visual surveys always remain a cheaper survey option, but unless those factors that affect detectability are accounted for they have limited value for monitoring. Despite the high capital cost of a combined visual-acoustic survey, lower running costs mean that relatively quickly it becomes the cheaper option out of the methods that do account for detectability, making it a cost-effective tool for monitoring. However, we acknowledge that excluding the data analysis costs from this analysis will cause variation in the number of surveys needed for the acoustic method to become the cheaper option out of all the survey methods. While acoustic survey data may be more analytically challenging than visual-only survey data and therefore increase the cost of a combined visual-acoustic survey, recent collaborations between survey teams in India and acoustic experts have greatly enhanced local analytical expertise thereby reducing data analysis costs (T. Akamatsu pers. comm. 2015). Furthermore, acoustic method capital costs have also been reduced through sharing of equipment between survey teams. We recommend that future studies investigate the data analysis time required according to expertise, and therefore cost, for each method for a more accurate comparison of methodological costs.

2.5.5. Limitations of acoustic surveys

While combined visual-acoustic surveys can overcome many of the availability and perception biases associated with visual surveys, factors affecting acoustic detectability are less well understood. Of the unmatched visual detections, most (20 of 23) were located either in Chittagong Port on the Lower Karnaphuli where there are considerable underwater barriers to acoustic detection created by ship hulls; or in high dolphin-density areas (visual group size >3) of the Sangu, where it is possible that observers overestimated group size. However, previous work suggests that accurate acoustic detection is negatively affected by higher dolphin densities (Akamatsu *et al*., 2008) as it becomes difficult to visually distinguish individual click trains under such conditions. We acoustically detected a maximum of five individuals within any given distance window, but without knowing the true number of dolphins it is difficult to determine whether this was a limitation of data loggers or overestimation by visual observers.

Acoustic detectability declines over distance at a rate determined by the detection threshold of data loggers, the level of unwanted noise, and the source level of the phonating dolphin (Akamatsu *et al*., 2008). We were unable to determine the maximum acoustic detection range in our study area as animals were unevenly distributed across the river width. In the Yangtze River, an acoustic detection range of 300 m has been achieved for finless porpoises using the same hydrophone array as described here (Akamatsu *et al*., 2008). We expect it is possible to achieve a minimum detection range of 300 m in Ganges River dolphin habitat where noise levels are similar or less than the Yangtze, and source levels between species are comparable (Akamatsu, 2008; Jensen *et al*., 2013).

While the sound beam of Ganges River dolphins is broad relative to other odontocetes, it is still relatively narrow and highly directional to facilitate prey discrimination in complex environments and under conditions of poor visibility (Jensen *et al*., 2013). Narrow beam width means that dolphins are only available for acoustic detection when oriented towards data loggers. While no acoustic studies have been carried out on the scanning behaviour of Ganges River dolphins, observations suggest that animals use changes in body orientation (e.g. side-swimming) and up-and-down head movements to increase their scan area (Herald *et al*., 1969). These behaviours mean that dolphins are constantly changing orientation and are therefore likely to be detected acoustically despite the narrow beam.

Despite there being a range of factors that negatively affect acoustic detection, consistently higher estimates of acoustic detectability indicate that these factors exert less of an effect than the factors affecting visual detection. Furthermore, the advantage of combined visual-acoustic surveys becomes more apparent when considering appropriate methods for surveying populations made up of small group sizes and in poor sighting conditions, factors that can reduce visual detectability (e.g. Smith *et al*., 2006; Braulik *et al*., 2012).

2.5.6. Recommendations for future surveys

The recent uplisting of the Yangtze Finless porpoise from Endangered to Critically Endangered by IUCN (Mei *et al*., 2012), and the threatened status of most of the world's other freshwater cetaceans, makes the identification of robust methods for estimating abundance for this group a priority. The single observer-team visual survey is a relatively cheap, easy-to-implement method that has been widely used. If all factors affecting detectability could be kept constant, count data from these surveys could be treated as a relative index of abundance. However, many factors, some of which cannot be easily controlled, can affect detectability. For example, population declines can themselves affect detectability if accompanied by a reduction in mean group size, so that any interpretation of trends in count data from visual surveys can be misleading (McConville *et al*., 2009).

There is growing evidence for the efficacy of combined visual-acoustic surveys as a monitoring tool for freshwater cetaceans. However, in order to optimise this method, future studies need to: focus on improving the matching of acoustic and visual detections; investigate whether the accuracy of acoustic counts is density-dependent; and investigate the variability in detection range for multiple species and how this is affected by variable levels of noise typically encountered in freshwater habitats.

2.5.7. Conclusion

Freshwater cetaceans are one of the most threatened groups of mammals. Identification of robust methods for estimating population size and trend detection is therefore an important priority to accurately identify populations for conservation attention, and assess the effectiveness of management interventions. A range of methods are already used to try to achieve these aims, but they either do not account for imperfect detectability (single observer-team visual surveys), or are unsuitable in shallow river systems (double observer-team visual surveys which require large boats for two independent teams), or are expensive and may not work well in some conditions (tandem-vessel visual survey where the two boats may have different fields of view). Combined visual-acoustic surveys can overcome many of the biases that negatively affect visual detection, thereby producing more precise and less biased estimates of abundance, and improved power to detect trends. We argue that barriers to acoustic surveys, such as technical expertise and cost, can be overcome through regional collaborations and sharing of equipment, making such surveys practical and cost-effective for NGOs or governments.

Chapter 3. Temporal patterns in the abundance of the Ganges River dolphin in southern Bangladesh.

The winter 2012 survey team

3.1. Abstract

Evidence-based conservation requires robust information on abundance and trends over time. Freshwater cetaceans are one of the most threatened groups of mammals on earth; however, there is a paucity of studies describing population trends for these species. Issues with detecting long-term trends partly arise from the use of inconsistent methods over time. Using a series of correction factors developed from boat-based surveys in winter 2012, I correct winter 1999 and late autumn 2011 surveys of Ganges River dolphins (*Platanista gangetica gangetica*) in southern Bangladesh for factors affecting detectability, producing an up-to-date abundance estimate and a review of seasonal differences and long-term trends in abundance. I found evidence of a significant change in seasonal abundance between late autumn and winter, suggesting that the Karnaphuli-Sangu rivers complex subpopulation of Ganges River dolphins is not isolated. This was further supported by sightings of Ganges

River dolphins in coastal waters (the first records of this in marine water). The comparison of abundance estimates from winter 1999 and winter 2012 revealed no significant change in long-term abundance, though there was uncertainty in the historical abundance estimate. The data on long-term trends presented here suggest that either; 1) levels of mortality are sustainable, 2) the Karnaphuli-Sangu rivers complex represents a 'sink' relying on immigration from a separate source subpopulation, 3) or there is a decline in abundance which is not yet detectable. The results of this study highlight the need to re-define the spatial boundaries for future monitoring so that they encompass coastal waters. The significant changes in seasonal abundance demonstrated here have important implications for spatial management of this small subpopulation.

3.2. Introduction

Evidence-based conservation requires robust information on species or population abundance and trends over time. Accurate detection of population trends can contribute to assessments of sustainability of a harvest (Green *et al*., 2005), and the effectiveness of management strategies such as newly established protected areas (Wilson *et al*., 2004). Similarly, detection of seasonal trends can provide useful information on migration patterns and potential barriers to dispersal, which is important for spatial conservation planning (Margules and Pressey, 2000; Natoli *et al*., 2005). In particular, such information can be essential for determining whether populations of interest are open or closed to migration of individuals beyond a defined study area, and can therefore help to define the spatial scale of management activities that may be required to protect such populations effectively (Woodroffe and Ginsberg, 1998; Mora and Sale, 2002).

Robust estimates of abundance and trends are often difficult to obtain given heterogeneous detection of individuals within and between surveys (Kéry and Schmidt, 2008; Kéry *et al*., 2009; Thompson *et al*., 2002). Over time there has been considerable effort in developing improved methods for monitoring. However, changes in monitoring methods between surveys can complicate the detection of trends over time. Where adequate information exists regarding historical survey conditions (e.g. sighting conditions, survey effort), abundance estimates can be adjusted using correction factors to account for variable detectability. Correction factors have been used to improve the accuracy of group size estimates (Barlow, 2006); account for animals unavailable for detection (Marsh and Sinclair, 1989; Kreb, 2002; Braulik, 2006); and account for variation in sighting rates caused by variable sighting conditions (Evans and Hammond, 2004).

Freshwater cetaceans are one of the most threatened groups of mammals on earth (Reeves, Smith and Kasuya, 2000). They face wide-scale threats from entanglement in fishing gear, pollution, and habitat loss and degradation (e.g. Smith *et al*., 2001; Turvey *et al*., 2010b). The status of most species is of concern due to high levels of observed mortality (Reeves *et al*., 2000; Beasley, 2007) and observed range collapses (Turvey *et al*., 2010a). However, few studies of freshwater cetaceans have had sufficient power from which to detect both long-term and seasonal trends, impeding conservation planning and potentially preventing early detection of population declines before critical levels are reached (Huang *et al*., 2012). There has been particular recent concern over the impact of fragmentation and isolation of populations of freshwater cetaceans. For example, wide-scale dam construction in the Mekong River has resulted in the isolation of a small population of Irrawaddy dolphins, *Orcaella brevirostris* (< 100 individuals; Ryan *et al*., 2011). Similarly, the Ganges River dolphin, *Platanista gangetica gangetica,* a subspecies of the South Asian River dolphin, risks extirpation in Nepal following construction of the Kalaishpuri Dam near the Nepal/India border resulting in population isolation (Smith and Braulik, 2008). The 'true' or obligate river dolphins (i.e. South Asian River dolphin; Amazon River dolphin, *Inia geoffrensis*; Araguaia River dolphin, *I. araguaiaensis*; Yangtze River dolphin, *Lipotes vexillifer*) are entirely restricted to freshwater with no known reports of these species entering marine waters (i.e. > 30 parts per thousand [ppt]), making them particularly vulnerable to physical barriers in rivers (such as dams and barrages).

A small, apparently isolated, subpopulation of Ganges River dolphins occurs in southern Bangladesh within four interconnected waterways collectively referred to as the Karnaphuli-Sangu rivers complex (Smith *et al.* 2001). Encounter rates are high relative to other parts of the species' range, prompting the suggestion that a protected area should be established in this system (Ahmed, 2004). The Karnaphuli-Sangu rivers complex is geographically isolated from the main part of the species' range (i.e. the Ganges-Meghna-Brahmaputra rivers complex) by a 75 km section of the Bay of Bengal. It is thought that the Bay of Bengal represents a barrier to dispersal between the two river complexes (Ahmed, 2000), as the species has never been sighted outside of river channels or at salinities greater than 23 ppt (Smith and Braulik, 2008). Smith *et al*. (2001) suggested that dolphins might migrate between the two river complexes during the monsoon when salinity in the Bay of Bengal is at its lowest. Such migration would likely lead to seasonal changes in the distribution or abundance of dolphins in the Karnaphuli-Sangu rivers complex; however, to date no evidence has been found to support this hypothesis.

In this study, I produce an up-to-date abundance estimate for the Karnaphuli-Sangu rivers subpopulation of Ganges River dolphins. Using a series of correction factors, I correct historical surveys for factors affecting detectability, and use these revised survey data to look for evidence of seasonal differences and long-term trends in abundance. I also present the results of coastal surveys during which I looked for evidence to support the hypothesis that the Karnaphuli-Sangu rivers complex is an open population.

3.3. Methods

3.3.1. Study area

Surveys covered a 45 km section of the Sangu River, a 20 km section of the Halda River, all 75 km of the Karnaphuli River, and the 29 km of the Shikalbaha-Chandkhali Canal (representing all four waterways within the Karnaphuli-Sangu rivers complex), and a 14 km stretch of coastline between the Karnaphuli (hereafter divided into the Upper and Lower Karnaphuli at Kalurghat Bridge, based on differences in river morphology and land use) and Sangu (hereafter divided into the Upper and Lower Sangu at Dohazari Bridge, based on differences in river morphology) rivers (Figure 3.1). Surveys largely covered the same area but low water levels in winter 2012 prohibited the navigation of a survey vessel between Chandanaish and the Dohazari Bridge on the Sangu River (Figure 3.1). This area was excluded from the survey, but interviews with local fisher communities located along this river section confirmed that dolphins only occupy this stretch of the Sangu during the summer (mid-April to mid-June) and monsoon season (mid-June to mid-August).

I carried out surveys in early November 2011 (during the late autumn season, also known as post-monsoon) and January to February 2012 (winter season or dry season). During the late autumn, water levels are still falling following the monsoon rains; by the winter they have reached their lowest levels. Both seasons provide optimal conditions for visual surveys of river dolphins as the negative effect of rain and wind on sighting conditions is minimal (Smith and Reeves, 2000).

Included in the following analysis is survey data from a historical survey carried out by Smith *et al*. (2001) in winter 1999. The winter 1999 survey broadly covered the same areas as the winter 2012 survey, but included sections of river between Sattar Ghat and Nazirhat on the Halda River, Chandanaish to Dohazari Bridge on the Sangu River, and Kaptai Lake in the Upper Karnaphuli River (Figure 3.1). Kaptai Lake was excluded from the winter 2012 survey as it was not possible to obtain research permits for the region. However, interviews with Kaptai Lake fishers indicated that dolphins had not been seen in the lake for at least 20

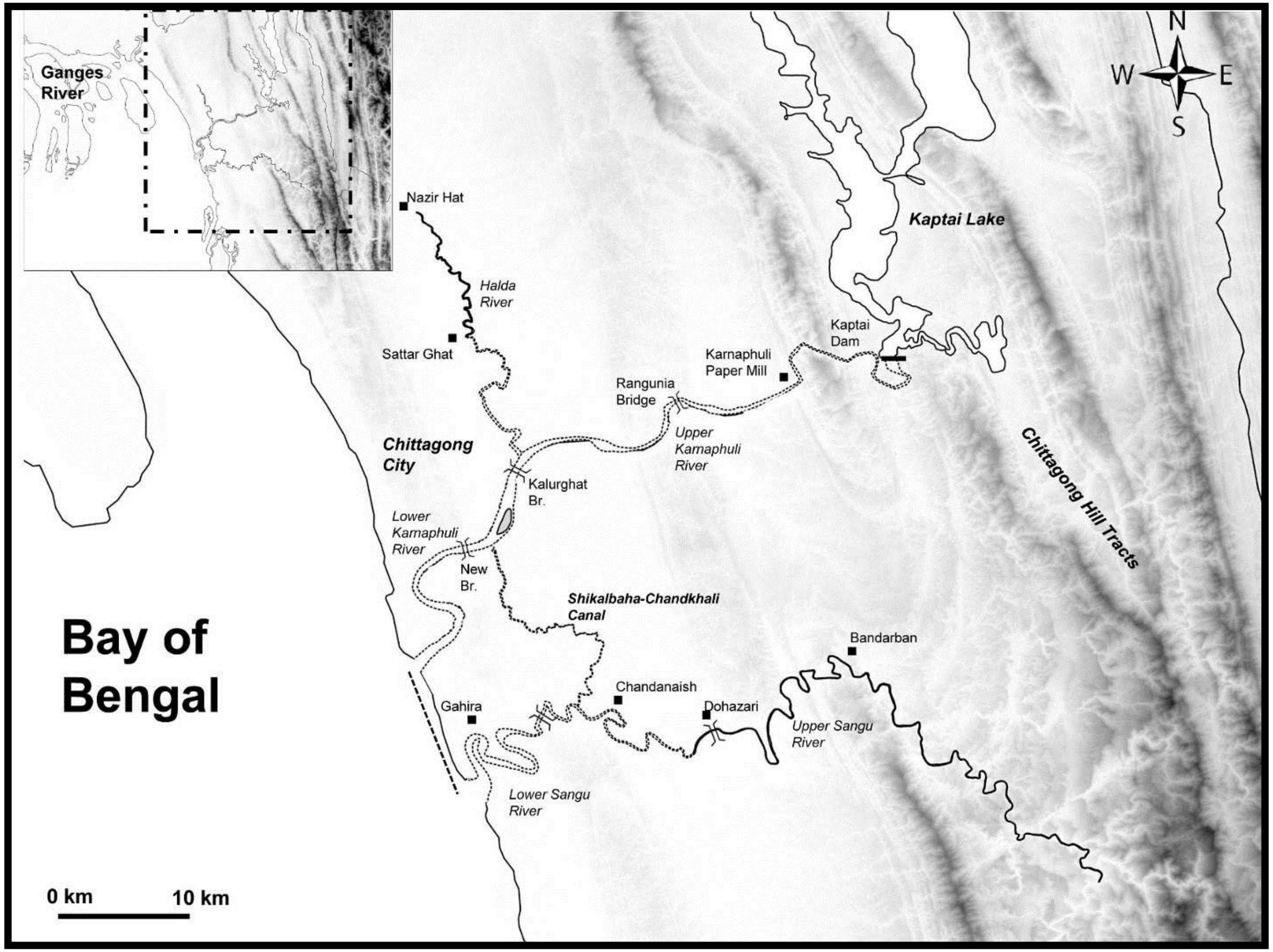

Figure 3.1: Map of the Karnaphuli-Sangu rivers complex (Halda, Karnaphuli and Sangu rivers and Shikalbaha-Chandkhali Canal) and the sections of waterway covered by the boat-based surveys (dotted outline). The dotted line along the coast indicates the approximate coastal transect covered during the winter 2012 survey (2012.1). The inset map shows the location of the Karnaphuli-Sangu rivers complex (dotted outline box) in relation to the Ganges River.

years, supporting the findings of Smith *et al*. (2001) who also failed to find any dolphins here. The last known reliable sighting of a dolphin in Kaptai Lake was in 1994 when the Rangamati Fisheries Research Institute recovered a dead individual (Ahmed, 2000).

3.3.2. Survey methods

Three replicate surveys were carried out in winter 2012, one using the combined visual-acoustic survey method (2012.1.cva; Table 3.1) and two using the single observer-team visual survey method (2012.2.so and 2012.3.so; Table 3.1). Based on the relatively small daily migrations made by Ganges River dolphins during the winter/ dry season (Braulik *et al*., 2006), it was assumed there was no movement of dolphins between rivers between surveys as replicate surveys were typically within a couple of hours/ days of each other. The combined visual-acoustic survey was carried out using the methods described in chapter two section 2.2.3. The single observer-team visual surveys followed the same procedures as described for the visual component of the combined visual-acoustic survey. The only factor that differed between the single observer-team visual surveys, were observer effort, strip width and the definition of group size (Table 3.1). During all three 2012 surveys, the Lower Karnaphuli River was split into two survey strips (i.e. north strip and south strip) due to wide channel width (mean width 820 m). Both strips were surveyed simultaneously to avoid potential double counting of dolphins due to dolphin movement between strips had they been surveyed one after another. As only a single acoustic hydrophone array was available for the combined visual-acoustic survey, the north strip was surveyed using the single observer-team method and the south strip was surveyed using the combined visual-acoustic method. Only a single survey was carried in late autumn 2011 and winter 1999, both of which employed the single observer-team visual survey method.

3.3.3. Pilot surveys

Three pilot surveys were carried out using the single observer-team visual method, one in November 2011 (2011.p1.so) and two in January 2012 (2012.p1.so and 2012.p2.so). All pilot surveys were carried out under excellent sighting conditions and largely using the same procedures as described in section 2.2.3 in chapter two: the only difference was in strip width in the Lower Karnaphuli River where the entire channel was surveyed as a single strip, rather than two separate strips. The channel was surveyed as a single strip as it is wider than most other channels and so observer sighting distance could be estimated over a wider range of distances. Additionally, the Lower Karnaphuli River is the only river in which it can be assumed dolphins are distributed randomly across perpendicular sighting distances as

Table 3.1: Summary of definitions (group size and survey strip width) and methods employed (so = single observer-team visual survey, cva = combined visual-acoustic survey), and the number of observers used during each survey (winter 1999, late autumn 2011, winter 2012).

2012 (winter)	Survey number and method	Month	Group size definition	Number of forward-facing observers	Survey strip width
Halda River	2012.1.cva	February	Individuals within 100 m	3	Entire channel width
Shikalbaha-Chandkhali Canal	2012.1.cva	February	Individuals within 100 m	3	Entire channel width
Lower Sangu River	2012.1.cva	February	Individuals within 100 m	3	Entire channel width
Lower Karnaphuli River (south strip)	2012.1.cva	February	Individuals within 100 m	3	Mean = 420 m
Lower Karnaphuli River (north strip)	2012.1.so	February	Individuals within 100 m	3	Mean = 420 m
Upper Karnaphuli River	2012.1.cva	February	Individuals within 100 m	3	Entire channel width
Halda River	2012.2.so	January	Individuals within 100 m	3	Entire channel width
Shikalbaha-Chandkhali Canal	2012.2.so	January	Individuals within 100 m	3	Entire channel width
Lower Sangu River	2012.2.so	January	Individuals within 100 m	3	Entire channel width
Lower Karnaphuli River (south strip)	2012.2.so	January	Individuals within 100 m	3	Mean = 420 m
Lower Karnaphuli River (north strip)	2012.2.so	January	Individuals within 100 m	3	Mean = 420 m
Upper Karnaphuli River	2012.2.so	January	Individuals within 100 m	3	Entire channel width
Halda River	2012.3.so	February	Individuals within 100 m	3	Entire channel width
Shikalbaha-Chandkhali Canal	2012.3.so	February	Individuals within 100 m	3	Entire channel width
Lower Sangu River	2012.3.so	February	Individuals within 100 m	3	Entire channel width
Lower Karnaphuli River (south strip)	2012.3.so	February	Individuals within 100 m	3	Mean = 420 m
Lower Karnaphuli River (north strip)	2012.3.so	February	Individuals within 100 m	3	Mean = 420 m

Upper Karnaphuli River	2012.3.so	February	Individuals within 100 m	3	Entire channel width
2011 (late autumn)					
Halda River	2011.1.so	November	Individuals within 100 m	2	Entire channel width
Shikalbaha-Chandkhali Canal	2011.1.so	November	Individuals within 100 m	2	Entire channel width
Lower Sangu River	2011.1.so	November	Individuals within 100 m	2	Entire channel width
Lower Karnaphuli River (south strip)	2011.1.so	November	Individuals within 100 m	2	Mean = 420 m
Lower Karnaphuli River (north strip)	2011.1.so	November	Individuals within 100 m	2	Mean = 420 m
Upper Karnaphuli River	2011.1.so	November	Individuals within 100 m	2	Entire channel width
1999 (winter)					
Halda River	1999.1.so	January	Individuals within 500 m	1	Entire channel width
Shikalbaha-Chandkhali Canal	1999.1.so	January	Individuals within 500 m	3	Entire channel width
Lower Sangu River	1999.1.so	January	Individuals within 500 m	3	Entire channel width
Lower Karnaphuli River	1999.1.so	January	Individuals within 500 m	3	Whole river following a zig-zag transect (mean = 820 m)
Upper Karnaphuli River	1999.1.so	January	Individuals within 500 m	3	Entire channel width

river depth is constant across the channel: constant river depth avoids the clustering of dolphins in a central deep channel which is commonly observed during freshwater cetacean surveys (see chapter two). To estimate an effective strip width, numbers of visual detections were plotted at perpendicular sighting distances from 0 to 399 m. Visual inspection of the numbers of visual detections over perpendicular sighting distances (Figure 3.2), revealed a significant decline in the number of detections beyond 199 m and so an strip width of 400 m (i.e. two half strip widths of 200 m) was selected.

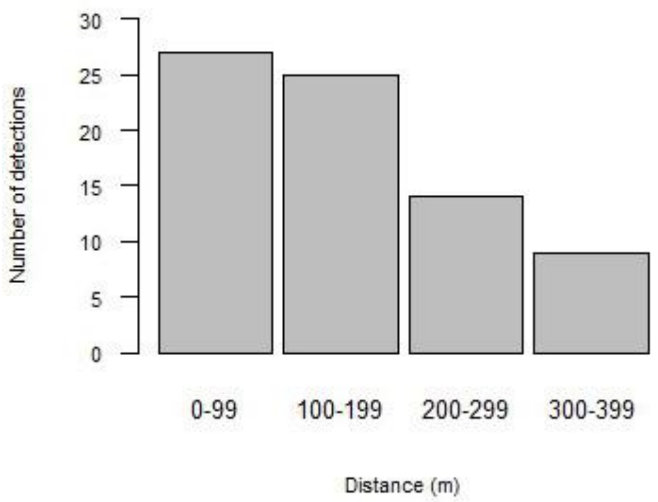

Figure 3.2: Numbers of visual detections over a perpendicular sighting distance of 399 m based on visual detection data from the three pilot surveys.

Data from the pilot surveys were also used to develop correction factors (see section 3.3.5) and to determine the distribution of dolphins throughout the study area and therefore the spatial extent of surveys.

3.3.4. Abundance estimation for the combined visual-acoustic survey

Visual and acoustic data were analysed using the closed-population, capture-recapture, Huggins conditional likelihood model (Huggins, 1989; 1991). Visual detections were treated as captures and acoustic detections were treated as recaptures. Visual and acoustic detections were matched using the method described in section 2.2.5 in chapter two.

3.3.4.1. Model assumptions

Closed-population, capture-recapture models require that the following assumptions be met:

1. Population closure: as both the capture (i.e. visual detection) and recapture (i.e. acoustic detection) events occurred almost simultaneously, it could be assumed that

there was no opportunity for births, deaths or permanent immigration or emigration to occur.

2. Captures are not overlooked or lost: this assumption might be violated if animals are not matched correctly. To establish which visual and acoustic detections were matched and which were unique, visual and acoustic detections were matched based on their location at the time of detection while allowing for movement between detection events based on knowledge of the dolphin's swim speed (see chapter two section 2.2.5 for details). Captures may be lost if animals captured during the first sampling event move considerably before the second sampling event thereby exceeding the distance threshold used for matching individuals. As discussed in chapter two section 2.3.2, it is unlikely that incorrect matching of detections constituted a significant source of bias in this study.

3. All animals have an equal probability of capture: in chapter two it was demonstrated that individual detection probabilities can vary within a sampling event as a result of available observation distance. Potential violation of this assumption was overcome by modelling abundance using the Huggins conditional-likelihood model (Huggins 1989, 1991). An advantage of the Huggins model over the Chapman-modified Lincoln-Petersen estimator is that detectability can be modelled as a function of predictor variables.

Freshwater cetacean abundance is typically modelled using groups to satisfy the assumption of independence between detections as it is assumed that individuals in a group of two or more individuals have a higher probability of being detected than a single animal. In contrast to other capture-recapture studies of freshwater cetaceans (e.g. Smith *et al*., 2006; Braulik *et al*., 2012b), abundance was estimated for individuals rather than groups for the following reasons:

1. Results from this study show no effect of group size on individual detectability (see section 3.4.2.1).

2. The majority (72%, n=83/116) of visual detections were of single animals (see section 3.4.2).

3. Acoustic detections were of individuals rather than groups.

4. Estimates of available observation distance were made for individual animals rather than groups.

Where visual detections were of groups larger than one, multiple entries were created for each group depending on how many individuals were visually detected within a group.

3.3.4.2. Detectability and abundance

Only a single predictor variable (available observation distance) was included in the models for waterway detection probabilities based on the results from chapter two. While studies of marine cetaceans have demonstrated an effect of observer experience on visual detectability (e.g. Barlow *et al*., 2006), results from chapter two indicate no effect of experience. Similarly, while group size is known to be an important predictor of visual detectability (Smith *et al*., 2006; Braulik *et al*., 2012b) it was excluded from the model as it was found to have no effect on detectability (see section 3.4.2).

Detection probabilities ($\hat{P}$) and abundance ($\hat{N}$) were modelled using the Huggins model (Huggins, 1989; 1999) for two sampling occasions in the program MARK (White and Burnham, 1999). Visual detection probabilities were modelled for individual waterways as a function of available observation distance (continuous factor), except for the Lower Karnaphuli where it was not possible to estimate available observation distance due to the high density of cargo ships (see chapter two for details). Models of acoustic detectability excluded the predictor variable (i.e. available observation distance) as it is only applicable to visual detections. Values for available observation distance differed by 1.3 orders of magnitude (i.e. 70 to 2,200 m), and so values were standardised to ensure the numerical algorithm was optimised for finding the correct parameter estimates (Cooch and White, 2002). Two models were fitted for each waterway: the null model and the model including available observation distance as a predictor. Models were ranked according to Akaike's information criterion (AIC), and model selection was based on ΔAIC (the difference in AIC between each model and the model with the lowest AIC; Burnham and Anderson, 2002). Detection probabilities and abundance were not estimated for the Upper Karnaphuli River as there were too few visual detections in this river section.

3.3.5. Correction factors for the single observer-team visual surveys

Each survey yields a best estimate of relative abundance based on the number of animals visually detected by the observer team. However, these estimates of relative abundance are not comparable with the estimate of absolute abundance from the combined visual-acoustic survey due to variation in survey methods which will influence detectability (i.e. differences in observer effort, differences in strip width in the Lower Karnaphuli, lack of simultaneous acoustic effort; see Table 3.1). To make estimates of abundance comparable, a series of correction factors were developed to correct visual counts from single observer-team visual surveys for animals that were missed.

Three factors were identified that influenced the detectability of animals between surveys, thereby limiting the comparability of abundance estimates over time: observer effort, strip width and acoustic effort (see Table 3.1 for details). Both observer effort and strip width correction factors were developed and applied to best estimates of the number of visually detected individuals, providing a corrected number of visually detected individuals. The acoustic effort correction factor was developed to account for individuals not detected by observers due to availability and/or sighting biases, and was applied to visual counts to produce an estimate of absolute abundance.

3.3.5.1. Observer effort correction factor

An observer effort correction factor was developed to correct visual counts for the reduction in observer effort between the late autumn 2011 survey and the winter 2012 survey (see Table 3.1) and the Halda 1999 survey and the winter 2012 survey (see Table 3.1). Separate observer effort correction factors were developed for the late autumn 2011 and winter 1999 surveys. For the late autumn 2011 survey, the observer effort correction factor accounted for a reduction in effort from three to two observers, while for the winter 1999 survey of the Halda the correction factor had to account for a further reduction to only a single observer.

The difference between a team of three and a team of two observers is the presence of a central observer who is responsible for scanning the front 10º either side of the transect line. To investigate the effect of the central observer on the overall number of detections, a single observer-team visual survey was carried out of the entire study area during the pilot phase using a team of three forward-facing observers. On each occasion a dolphin was sighted, the data recorder encouraged other observers not to change their search behaviour. If another observer sighted the same dolphin then this was noted by the data recorder so as to determine which sightings were unique to a single observer. The observer effort correction factor ($\hat{f}_1$) for the loss of only one observer was calculated for individual waterways using the following equation:

$$\hat{f}_1 = n_{vqs} / n_{vs} \quad \text{\{where } s = 2012.p1\text{; see Table 3.2\}} \qquad [3.1]$$

where 1 denotes the loss of one observer, s denotes the survey number, n_v denotes the number of detections made using the visual method with a team of three observers, n_{vq}

denotes the number of visual detections unique to only the left and right observers (i.e. two observers).

Table 3.2: Definition of subscripts used in the equations for estimation of correction factors and abundance.

Subscript	Definition
s	Survey, where: *2012.1* = 2012 winter survey, replicate one using the combined visual-acoustic method except for the north strip of the Lower Karnaphuli which was surveyed using the single observer-team visual method *2012.2* = 2012 winter survey, replicate two using the single observer-team visual method *2012.3* = 2012 winter survey, replicate three using the single observer-team visual method *2012.p1* = 2012 winter pilot survey, replicate one using the single observer-team visual method *2012.p2* = 2012 winter pilot survey, replicate two using the single observer-team visual method *2011.p1* = 2011 late autumn pilot survey, replicate one using the single observer-team visual method *2011.1* = 2011 late autumn survey, replicate one using the single observer-team visual method *1999.1* = 1999 winter survey, replicate one using the single observer-team visual method.

Given the greater reduction in observer effort between the winter 1999 Halda River survey and the winter 2012 surveys (i.e. a difference of two observers; Table 3.1), a corrected visual count was estimated using an alternative method. No empirical data were available from the winter 2012 surveys from which to derive a correction factor for the loss of two forward-facing observers, and so correction was based on assumption. During one of the winter 2012 pilot surveys, a single rear-facing observer was used in addition to the three forward-facing observers. The observer effort correction factor for the loss of two observers was calculated for individual waterways and was based on the proportion of visual detections made by the single rear-facing observer that matched the visual detections made by the three forward-facing observers:

$$\hat{f}_2 = n_{vrs} / n_{vs} \text{ \{where } s = 2012.p2\text{; see Table 3.2\}} \qquad [3.2]$$

where 2 denotes the loss of two observers, n_{vr} denotes the number of visual detections made by the rear-facing observer that match the detections made by the three forward-facing observers. By using visual detections made by rear and forward-facing observers, it is assumed that each animal has the same probability of detection by forward and rear-facing observers. A number of factors are likely to invalidate this assumption: 1) dolphins may display vessel avoidance behaviour by increasing dive time as the vessel passes by, thereby decreasing the probability of detection by the rear observer; 2) sighting conditions (e.g. sun glare) will differ for the forward and rear-facing observers; and 3) the available observation distance (see chapter two for details) will differ. However, it is assumed that the negative effect of factors two and three are unlikely to be biased towards either observer-team. Factor one will negatively affect the detectability of animals for the rear-facing observer, and so it is assumed that the correction factor for the Halda River is likely to be an overestimate.

Visual counts from the individual waterways surveyed in late autumn 2011 and the winter 1999 Halda River survey, were corrected ($\hat{n}_v$) by dividing the visual count by the mean observer effort correction factor from across all waterways. By using the mean correction factor it is assumed that the difference between one or two observers and a team of three is the same across waterways. This assumption is likely to be met as the observer team remained constant across surveys of each waterway. The CVs for each of the observer effort correction factors were derived from the variance of the mean correction factor from all waterways.

3.3.5.2. Strip width correction factor

During the winter 1999 survey of the Lower Karnaphuli River, the channel was surveyed as a single strip in which the survey vessel alternated arbitrarily between the outer edges of the strip. This represents a near doubling of the survey strip width relative to the winter 2012 surveys from a mean of 420 m to 820 m (see Table 3.1), and therefore a probable decline in the visual detectability of dolphins. To assess the effect of strip width on visual detectability, the perpendicular sighting distance of all visual detections made during the three pilot surveys of the Lower Karnaphuli River, were plotted at 100 m intervals up to 399 m. The correction factor for strip width ($\hat{f}_x$) was calculated for the Lower Karnaphuli River as follows:

$$\hat{f}_x = n_{vs} / n_{vis} \quad \text{\{where } s = \mathit{2012.p1, 2012.p2, 2011.p1}\text{; see Table 3.2\}} \qquad [3.3]$$

where n_{vi} represents the inflated number of visual detections where the number of detections between 200 - 399 m is inflated to match the number of detections between 0 - 199 m. This correction factor is based on two assumptions: 1) dolphins are evenly distributed across the strip width, and 2) there is 100% visual detectability in a half strip width of 0 - 199 m division. Both assumptions were met as detailed in section 3.3.3.

The corrected visual count for the winter 1999 survey of the Lower Karnaphuli River was calculated by dividing the visual count by the mean strip width correction factor from the three pilot surveys. The CV of the strip width correction factor was derived from the variance of the mean correction factor from the three pilot surveys.

3.3.5.3. Acoustic effort correction factor

An acoustic effort correction factor was developed to account for animals missed during surveys where there was no simultaneous acoustic effort. The acoustic effort correction factor ($\hat{f}_a$) was developed for individual waterways and calculated as follows:

$$\hat{f}_a = \hat{N}_s / n_{vs} \quad \text{\{where } s = 2012.1\text{; see Table 3.2\}} \qquad [3.4]$$

where $\hat{N}$ denotes abundance and a denotes the acoustic method.

Coefficients of variation for the acoustic effort correction factors were derived from the variance of the correction factor, where:

$$\mathrm{var}(\hat{f}_a) = \frac{\mathrm{var}(\hat{N}_{2012.1})}{n_{v2012.1}^{\;2}} \qquad [3.5]$$

3.3.6. Abundance estimation for winter 2012

3.3.6.1. Abundance estimation for the winter 2012 replicate surveys

Abundance for waterways surveyed using the single observer-team visual method, was estimated by multiplying the visual count by the waterway-specific acoustic correction factor (see Table 3.3). Assuming independence of the variables (i.e. acoustic effort correction factors and number of visual detections), variance of waterway abundance was estimated using the delta method (Buckland *et al*. 1993):

$$\mathrm{Var}(\hat{N}_s)^2 = N_s^2 \left(\frac{\mathrm{var}(\hat{f}_a)}{f_a^2} + \frac{\mathrm{var}(\overline{n}_{v2012})}{\overline{n}_{v2012}^2} \right) \text{\{where } s = 2012.2, 2012.3\text{; see Table 3.2\}} \; [3.6]$$

where $\overline{n}_{v2012}$ is the mean number of visual detections across the three winter 2012 surveys for a specific waterway.

Table 3.3: Summary of the correction factors applied to visual counts from each waterway, along with final equations used to estimate abundance for each of the single observer-team visual surveys from winter 2012, late autumn 2011, and winter 1999.

Waterway	Survey	Correction factors				Abundance ($\hat{N}$)
		Observer effort minus 1 observer ($\hat{f}_1$)	Observer effort minus 2 observers ($\hat{f}_2$)	Strip width ($\hat{f}_x$)	Acoustic effort ($\hat{f}_a$)	
Halda	2012.2.so & 2012.3.so	x	x	x	✓	$\hat{N} = \hat{f}_a n_v$
Shikalbaha-Chandkhali	2012.2.so & 2012.3.so	x	x	x	✓	$\hat{N} = \hat{f}_a n_v$
Sangu	2012.2.so & 2012.3.so	x	x	x	✓	$\hat{N} = \hat{f}_a n_v$
Lower Karnaphuli	2012.2.so & 2012.3.so	x	x	x	✓	$\hat{N} = \hat{f}_a n_v$
Halda	2011.1.so	✓	x	x	✓	$\hat{N} = \hat{f}_a (n_v / \overline{f}_1)$
Shikalbaha-Chandkhali	2011.1.so	✓	x	x	✓	$\hat{N} = \hat{f}_a (n_v / \overline{f}_1)$
Sangu	2011.1.so	✓	x	X	✓	$\hat{N} = \hat{f}_a (n_v / \overline{f}_1)$
Lower Karnaphuli	2011.1.so	✓	x	X	✓	$\hat{N} = \hat{f}_a (n_v / \overline{f}_1)$
Halda	1999.1.so	x	✓	X	✓	$\hat{N} = \hat{f}_a (n_v / \overline{f}_2 (n_v / \overline{f}_x))$
Shikalbaha-Chandkhali	1999.1.so	x	x	X	✓	$\hat{N} = \hat{f}_a n_v$
Sangu	1999.1.so	x	x	X	✓	$\hat{N} = \hat{f}_a n_v$
Lower Karnaphuli	1999.1.so	x	x	✓	✓	$\hat{N} = \hat{f}_a n_v$

The variance of $\overline{n}_{v2012}$ was the variance of the mean number of visual detections across the three winter 2012 surveys. The coefficients of variation (CV) of the waterway abundance estimates were calculated from the variance estimate. The CVs are likely to be underestimated because it is assumed there is zero covariance across the variables, yet these are positively correlated due to the shared value of n_v in $\hat{f}_a$ and $\overline{n}_{v2012}$.

Waterway abundance for the winter 2012 replicate one survey of the Lower Karnaphuli River was estimated differently to the rest of the waterway abundance estimates as it was the sum of the two abundance estimates: the south strip abundance estimate (surveyed using the combined visual-acoustic method) and the north strip abundance estimate (surveyed using the single observer-team visual method). The CV of the abundance estimate was calculated from the variance, where the overall variance was the sum of the variance estimates from the north and south strips. As with the CVs for the abundance estimates of the other waterways, the CV of the 2012.1 Lower Karnaphuli abundance estimate is likely to be underestimated due to positive covariance between the variances for each strip.

Total abundance for the study area for each of the winter 2012 surveys was calculated as the sum of abundance estimates from each waterway. The CV of the total abundance estimate was calculated from the variance estimate where total variance was the sum of variance estimates from each waterway. By summing variance estimates from each waterway it is assumed that variance estimates from each waterway are independent, an assumption that is met as there are no shared values between waterways.

Confidence limits were estimated using the following formula, assuming that the number of animals not captured ($\hat{f}_0$) follows a log-normal distribution and where the lower limit cannot be smaller than the total number of animals detected during the study (M_{t+1}) (Williams *et al*., 2002):

$$\text{Lower 95\% CL } (\hat{N}_s) = M_{t+1} + \left(\frac{\hat{f}_0}{C} \right) \qquad [3.7]$$

$$\text{Upper 95\% CL } (\hat{N}_s) = M_{t+1} + \left(\hat{f}_0 C \right) \qquad [3.8]$$

where:

$$\hat{f}_0 = \hat{N}_s - M_{t+1} \qquad [3.9]$$

and

$$C = \exp\left\{1.96\left[\ln\left(1+\frac{var\ (\hat{N}_s)}{\hat{f}_0^{\,2}}\right)\right]^{1/2}\right\} \qquad [3.10]$$

3.3.6.2. Mean abundance for winter 2012

Overall abundance estimates for waterways and the entire study area were based on the mean of the three winter 2012 surveys. The CVs were derived from the variance of the mean abundance estimate, where:

$$\mathrm{var}(\bar{N}_{2012}) = \mathrm{var}\left(\frac{1}{3}\sum_{s=1}^{3}\bar{N}_{2012,s}\right) \qquad [3.11].$$

Upper and lower log-normal confidence limits were estimated using equations 3.7 and 3.8.

3.3.7. Abundance estimation for late autumn 2011 and winter 1999

Waterway abundance estimates for the late autumn 2011 and winter 1999 surveys were calculated by multiplying corrected visual counts by the waterway-specific acoustic effort correction factor (see Table 3.3). Variances for each of the waterway abundance estimates were calculated using the delta method assuming independence between the variables:

$$\mathrm{Var}(\hat{N}_{2011.1})^2 = N_{2011.1}^2\left(\frac{\mathrm{var}(\hat{f}_a)}{\hat{f}_a^{\,2}} + \frac{\mathrm{var}(\bar{n}_{v2012})}{\bar{n}_{v2012}^{\,2}} + \frac{\mathrm{var}(\bar{f}_1)}{\bar{f}_1^{\,2}}\right) \qquad [3.12]$$

As there was only a single replicate of each waterway during the 2011 and 1999 surveys, the variance for the mean number of visual detections from the 2012 surveys was included in the waterway variance estimate for the 2011 and 1999 surveys: this assumes constant variance in the number of visual detections across survey years. As with the variance estimates for the 2012.2 and 2012.3 waterway abundance estimates, the assumption of independence between the variables is not met due to the shared value of n_v between in $\hat{f}_a$ and $\bar{n}_{v2012}$.

The variance estimates for the winter 1999 abundance estimates of the Sangu River and Shikalbaha-Chandkhali Canal were calculated using equation 3.6 as abundance was simply the product of the visual count and the acoustic effort correction factor. The variance estimates for the winter 1999 abundance estimates of the Halda and Lower Karnaphuli rivers were based on equation 3.6 but also included the variance for the loss of two observers correction factor $\overline{f}_2$ and strip width $\overline{f}_x$ respectively. Coefficients of variation for the waterway abundance estimates were calculated from the variance estimate. As with the CVs for the winter 2012 and the 2011 waterway abundance estimates, CVs for the 1999 waterway abundance estimates are likely to be underestimated due to the positive covariance between $\hat{f}_a$ and $\overline{n}_{v2012}$.

Abundance estimates from individual waterways were then summed to obtain an overall abundance estimate for the study area for both the 2011 and 1999 surveys. Overall variance estimates were calculated as the sum of variance estimates from each waterway, assuming independence between waterways. While the assumption of independence could be met for the 1999 variance estimate, it could not be met for the 2011 variance estimate due to the common correction factor for observer effort which was applied to each of the waterways. As a result of the non-independence between waterways, it is likely that the variance estimate for overall 2011 abundance was underestimated. Overall CVs were calculated from the overall variance estimates. Upper and lower log-normal confidence limits were calculated using equations 3.7 and 3.8.

3.3.8. Trends

3.3.8.1. Seasonal differences and sensitivity analysis

The late autumn 2011 abundance estimate was compared to the winter 2012 abundance estimate to look for evidence of seasonal differences in dolphin abundance. To evaluate the influence of correction factors on resulting trends, a sensitivity analysis was carried out in which seasonal differences were explored under the following two scenarios: 1) comparison of the lowest late autumn 2011 abundance estimate and the highest winter 2012 abundance estimate; and 2) comparison of the highest late autumn 2011 abundance estimate and the lowest winter 2012 abundance estimate. Low and high abundance were estimated by applying the lowest and highest estimated correction factors from across waterways for acoustic effort and observer effort (2 vs 3 observers). To test for significant differences between abundance estimates, I calculated the 95% confidence interval for the difference between the two group means to determine if confidence intervals overlapped zero.

3.3.8.2. Long-term trends and sensitivity analysis

Estimates of abundance from the winter 1999 survey and winter 2012 surveys were compared to look for evidence of long-term change in abundance. As with the seasonal trend analysis, a sensitivity analysis was carried out to assess the influence of correction factors on resulting trends. Long-term trends were compared under two scenarios: 1) comparison of the lowest winter 1999 abundance estimate against the highest winter 2012 abundance estimate; and 2) comparison of the highest winter 1999 abundance estimate against the lowest winter 2012 abundance estimate. Low and high abundance were estimated by applying the lowest and highest combination of corrections factors respectively. In contrast to the low and high estimates for the observer effort and acoustic effort correction factors, the low and high estimates for the strip width correction factor were derived from the three pilot surveys of the same waterway (i.e. the Lower Karnaphuli River).

3.3.9. Coastal surveys

The coastal region between the Karnaphuli and Sangu river mouths was surveyed for Ganges River dolphins using the single observer-team visual method but with no constraints on strip width. In addition to the Ganges River dolphin, there are seven species of dolphin and porpoise that occur in this region of Bangladesh, including: Irrawaddy dolphins; Indo-pacific finless porpoises (*Neophocaena phocaenoides*); Indo-Pacific humpback dolphins (*Sousa chinensis*); Pantropical spotted dolphins (*Stenella attenuata*); Spinner dolphins (*Stenella longirostris*); and Indo-pacific bottlenose dolphins (*Tursiops aduncus*). Ganges River dolphins can be differentiated from other species by their distinctive elongated rostrum and reduced dorsal fin. On any occasion a dolphin or porpoise was sighted, the survey vessel was stopped for up to 20 minutes, allowing observers to confirm species and group size and take salinity measurements.

3.4. Results

3.4.1. Correction factors

There was little difference in the estimated correction factor for each waterway for the loss of a single observer, with values ranging from 0.89 to 1.0. The greatest difference between a team of two or three observers was in the Lower Karnaphuli River (i.e. 0.89), while in the Halda River and Shikalbaha-Chandkhali Canal the loss of the central observer had no impact on the overall number of detections (i.e. 1.0). The mean observer effort correction factor for the loss of a single observer was 0.95 (CV = 6.1%; Table 3.4).

The loss of two observers had a much greater overall effect on the number of detections with correction factor values ranging from 0.37 to 0.47. The greatest difference between a team of three and team of one was in the Lower Karnaphuli River and the Shikalbaha-Chandkhali Canal where the single rear-facing observer detected only 37% of the detections made by the three forward-facing observers. The smallest difference was in the Halda River where the rear-facing observer detected 47% of the detections made by the forward-facing observers. The mean observer effort correction factor for the loss of two observers was 0.4 (CV = 11.8%; Table 3.4).

The strip width correction factors for each of the pilot surveys of the Lower Karnaphuli River were 0.62, 0.71 and 0.75 resulting in a mean correction factor of 0.69 (CV = 9.6%; Table 3.4) which was applied to the visual count from the Lower Karnaphuli 1999 winter survey.

Acoustic effort correction factors ranged from 1.5 (CV=4.6%) for the Shikalbaha-Chandkhali Canal to 1.8 (CV=8.9%) for the Halda River (Table 3.4). No observer effort or acoustic effort correction factors were calculated for the Upper Karnaphuli River as there were too few detections.

3.4.2. Abundance estimates winter 2012

3.4.2.1. Combined visual-acoustic survey

Numbers of visual and acoustic detections were highest in the Lower Karnaphuli and Sangu rivers (Table 3.4). Only three individuals were acoustically detected in the Upper Karnaphuli River, none of which were detected visually (Table 3.4). The majority of visually detected groups were of single animals (n=83/116) followed by six groups of two and four groups of three. Only a single group of four and five individuals were detected, both of which were in the lower reaches of the Sangu River. There was no significant difference (Mann-Whitney test, w = 3423, $p = 0.2346$) in the detection probability of single animals relative to a group size of two or more animals.

A comparison of AIC values for the models of detectability for the Halda River, Shikalbaha-Chandkhali Canal and Sangu River supported the model containing available observation distance producing abundance estimates of 27 individuals (CV = 8.9%, 95% CI: 26 - 38), 20 (CV = 4.6%, 95% CI: 20 - 25) and 84 (CV = 4.2%, 95% CI: 81 - 96) respectively (Table 3.4). For the Lower Karnaphuli River south strip, available observation distance was not offered as a possible predictor and so abundance was estimated as 33 (CV = 6.5%; Table 3.4).

During the survey of the Lower Karnaphuli River north strip (2012.1.so), 17 dolphins were detected visually (Table 3.4). The acoustic effort correction factor for the Lower Karnaphuli River south strip (1.57) was applied to the visual count in the north strip, resulting in an abundance estimate of 27 (CV = 9.8%; Table 3.4). The abundance estimates from the north and south strips were summed resulting in an overall abundance estimate for the Lower

Karnaphuli River of 60 individuals (CV = 5.7%, 95% CI: 55 - 69). Abundance for the entire study area was estimated as 194 individuals (CV = 2.9%, 95% CI: 185 - 208; Table 3.4).

3.4.2.2. Single observer-team visual surveys

Visual counts during each of the replicate winter 2012 single observer-team visual surveys, were not dissimilar to the visual counts made during the first replicate survey employing the combined visual-acoustic method (Table 3.4). Following correction of the visual counts with the acoustic effort correction, mean overall abundance was estimated as 194 (CV = 5.7%, 95% CI: 175 - 218) and 203 (CV = 5.7%, 95% CI: 183 - 229) for each of the surveys (Table 3.4).

3.4.2.3. Mean abundance winter 2012

A mean of the three winter 2012 surveys resulted in a final abundance estimate of 197 individuals (CV = 3%, 95% CI: 187 - 209; Table 3.4).

3.4.3. Late autumn 2011 abundance and seasonal differences

Following correction of the waterway visual counts with the waterway-specific acoustic and mean observer effort correction factors (each applied to all waterways), overall abundance was estimated as 92 individuals (CV = 7.4%, 95% CI: 80 - 107) for the late autumn 2011 survey (Table 3.4).

Significant differences in abundance were detected in the Sangu and Lower Karnaphuli rivers, where there is a greater abundance of dolphins during the winter season relative to the late autumn (Figure 3.3). While the varying combinations of the correction factors altered the late autumn abundance estimate by 27 individuals (low abundance = 80, high abundance = 107) and the winter 2012 abundance estimate by 26 individuals (low abundance = 185, high abundance = 211), this had no effect on the resulting trend. Differences in abundance are likely attributable to genuine differences in abundance as the major factors known to influence detectability (i.e. strip width, boat speed, observer effort, sighting conditions) were accounted for in the survey design or in the correction factors. Additionally, individual detectability is unlikely to have changed as a result of group size, as the majority of animals occurred singly with few groups exceeding two individuals (Figure 3.4).

Table 3.4: Summary data (n_v = number visual detections, n_a = number of acoustic detections, m = number of matched detections, P_v = visual detection probability, P_a = acoustic detection probability, m_{t+1} = number of unique individuals detected, f_a = acoustic correction factor, f_1 = observer effort correction factor for the loss of a single observer, f_2 = observer effort correction factor for the loss of two observers, f_x = strip width correction factor, visual encounter rate (individuals per linear km) and abundance) from the three winter 2012 surveys, one late autumn 2011 survey and one winter 1999 survey.

Survey	n_v	n_a	m	m_{t+1}	P_v (95% CI)	P_a (95% CI)	f_1 (CV)	f_2 (CV)	f_x (CV)	f_a (CV)	Visual encounter rate	Abundance (CV, 95% CI)
Halda 2012.1.cva	15	22	12	25	0.55 (0.34-0.74)	0.80 (0.53-0.93)	-	-	-	-	0.8	27 (CV = 8.9%, 95% CI: 26-38)
Halda 2012.2.so	17	-	-	-	-	-	-	-	-	1.80 (8.9%)	0..9	31 (CV = 16.0%, 95% CI: 24–44)
Halda 2012.3.so	13	-	-	-	-	-	-	-	-	1.80 (8.9%)	0.7	24 (CV = 16.0%, 95% CI: 19-34)
Halda 2012 mean	**15 (13.3%)**	**-**	**-**	**18**	**-**	**-**	**-**	**-**	**-**	**-**	**0.8**	**27 (CV = 8.2%, 95% CI: 24–33)**
Halda 2011.1.so	**16**	**-**	**-**	**-**	**-**	**-**	**0.95 (6.1%)**	**-**	**-**	**1.80 (8.9%)**	**0.8**	**31 (CV = 17.1%, 95% CI: 24 - 45)**
Halda 1999.1.so	**4**	**-**	**-**	**-**	**-**	**-**	**-**	**0.39 (11.8%)**	**-**	**1.80 (8.9%)**	**0.2**	**19 (CV = 19.9%, 95% CI: 13 - 28)**
Shikalbaha-Chandkhali 2012.1.cva	13	18	12	19	0.67 (0.43-0.84)	0.92 (0.61-0.99)	-	-	-	-	0.4	20 (CV = 4.6%, 95% CI: 20 - 25)
Shikalbaha-Chandkhali 2012.2.so	14	-	-	-	-	-	-	-	-	1.5 (4.6%)	0.5	21 (CV = 8.5%, 95% CI: 19 – 26)
Shikalbaha-Chandkhali 2012.3.so	15	-	-	-	-	-	-	-	-	1.5 (4.6%)	0.5	23 (CV = 8.5%, 95% CI: 20 – 28)
Shikalbaha-Chandkhali	**14 (7.1%)**	**-**	**-**	**16**	**-**	**-**	**-**	**-**	**-**	**-**	**0.5**	**21 (CV = 4.4%, 95% CI: 20 -**

2012 mean												**24)**
Shikalbaha-Chandkhali 2011.1.so	**14**	**-**	**-**	**-**	**-**	**-**	**0.95 (6.1%)**	**-**	**-**	**1.5 (4.6%)**	**0.5**	**23 (CV = 10.5%, 95% CI: 19-29)**
Shikalbaha-Chandkhali 1999.1.so	**18**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1.5 (4.6%)**	**0.6**	**27 (CV = 8.5%, 95% CI: 24-33)**
Sangu 2012.1.cva	50	69	41	78	0.62 (95% CI: 0.49-0.73)	0.82 (95% CI: 0.69-0.90)	-	-	-	-	1.1	84 (CV = 4.2%, 95% CI: 81 - 96)
Sangu 2012.2.so	44	-	-	-	-	-	-	-	-	1.68 (4.2%)	1.0	74 (CV = 9.5%, 95% CI: 63 - 91)
Sangu 2012.3.so	52	-	-	-	-	-	-	-	-	1.68 (4.2%)	1.2	88 (CV = 9.5%, 95% CI: 75 - 108)
Sangu 2012 mean	**49 (8.6%)**	**-**	**-**	**58**	**-**	**-**	**-**	**-**	**-**	**-**	**1.1**	**82 (CV = 4.7%, 95% CI: 76 - 91)**
Sangu 2011.1.so	**5**	**-**	**-**	**-**	**-**	**-**	**0.95 (6.1%)**	**-**	**-**	**1.68 (4.2%)**	**0.1**	**9 (CV = 11.3%, 95% CI: 8 - 12)**
Sangu 1999.1.so	**59**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1.68 (4.2%)**	**1.3**	**100 (CV = 9.5%, 95% CI: 85 - 123)**
Lower Karnaphuli south strip 2012.1.cva	21	27	17	31	-	-	-	-	-	-	-	33 (CV = 6.5%, 95% CI: 32 - 43)
Lower Karnaphuli north strip 2012.1.so	17	-	-	-	-	-	-	-	-	1.57 (6.5%)	-	27 (CV = 9.8%, 95% CI: 23 - 34)

Lower Karnaphuli TOTAL 2012.1	38	-	-	-	-	-	-	-	-	-	1.4	60 (CV = 5.7%, 95% CI: 55 - 69)
Lower Karnaphuli (south + north strip) 2012.2.so	42	-	-	-	-	-	-	-	-	1.57 (6.5%)	1.5	66 (CV = 9.8%, 95% CI: 57-83)
Lower Karnaphuli (south + north strip) 2012.3.so	44	-	-	-	-	-	-	-	-	1.57 (6.5%)	1.6	70 (CV = 9.8%, 95% CI: 59-87)
Lower Karnaphuli 2012 mean	**41 (7.4%)**	**-**	**-**	**45**	**-**	**-**	**-**	**-**	**-**	**-**	**1.5**	**65 (CV=6.0%, 95% CI: 59-75)**
Lower Karnaphuli 2011.1.so	**18**	**-**	**-**	**-**	**-**	**-**	**0.95 (6.1%)**	**-**	**-**	**1.57 (6.5%)**	**0.8**	**30 (CV = 11.6%, 95% CI: 25 - 39)**
Lower Karnaphuli 1999.1.so	**27**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.70 (9.3%)**	**1.57 (6.5%)**	**1.0**	**61 (CV = 13.6%, 95% CI: 49-82)**
Upper Karnaphuli 2012.1.cva	0	3	0	3	-	-	-	-	-	-	0	3
Upper Karnaphuli 2012.2.so	0	-	-	-	-	-	-	-	-	-	0	0
Upper Karnaphuli 2012.3.so	1	-	-	-	-	-	-	-	-	-	0.02	1
Upper Karnaphuli 2012 mean	-	-	-	-	-	-	-	-	-	-	-	2
Upper Karnaphuli 2011.1.so	0	-	-	-	-	-	-	-	-	-	0	0

Upper Karnaphuli 1999.1.so	6	-	-	-	-	-	-	-	-	-	0.1	6
TOTAL 2012.1	116	-	-	173	-	-	-	-	-	-	-	194 (CV = 3.0%, 95% CI: 185 - 207)
TOTAL 2012.2	118	-	-	118	-	-	-	-	-	-	-	193 (CV = 5.7%, 95% CI: 175 - 218)
TOTAL 2012.3	124	-	-	124	-	-	-	-	-	-	-	203 (CV = 5.7%, 95% CI: 183 - 229)
TOTAL 2012 mean	**120**	**-**	**-**	**139**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**197 (CV = 3.0%, 95% CI: 187 - 209)**
TOTAL 2011.1	**53**	**-**	**-**	**53**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**92 (CV = 7.4%, 95% CI: 80 - 107)**
TOTAL 1999.1	**114**	**-**	**-**	**114**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**212 (CV = 6.3%, 95% CI: 189 - 241)**

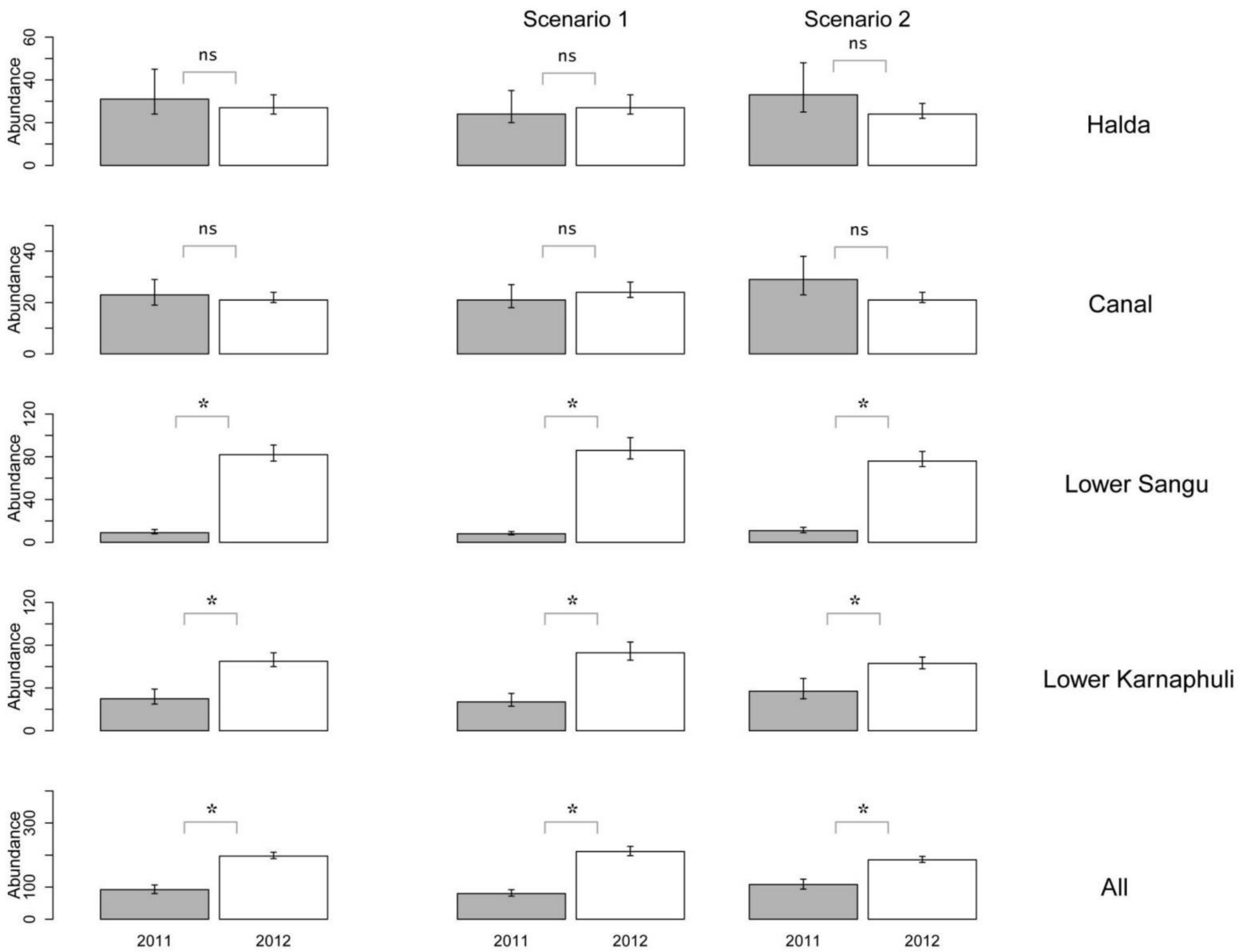

Figure 3.3: A comparison of seasonal (late autumn 2011 to winter 2012) differences in the abundance of Ganges River dolphins in the Karnaphuli-Sangu rivers complex. The left hand image represents modelled abundance estimates. The right hand images represent the results of the sensitivity analysis under scenario 1 (lowest late autumn 2011 abundance estimate compared to the highest winter 2012 abundance estimate) and scenario 2 (highest late autumn 2011 abundance estimate compared to the lowest winter 2012 abundance estimate).

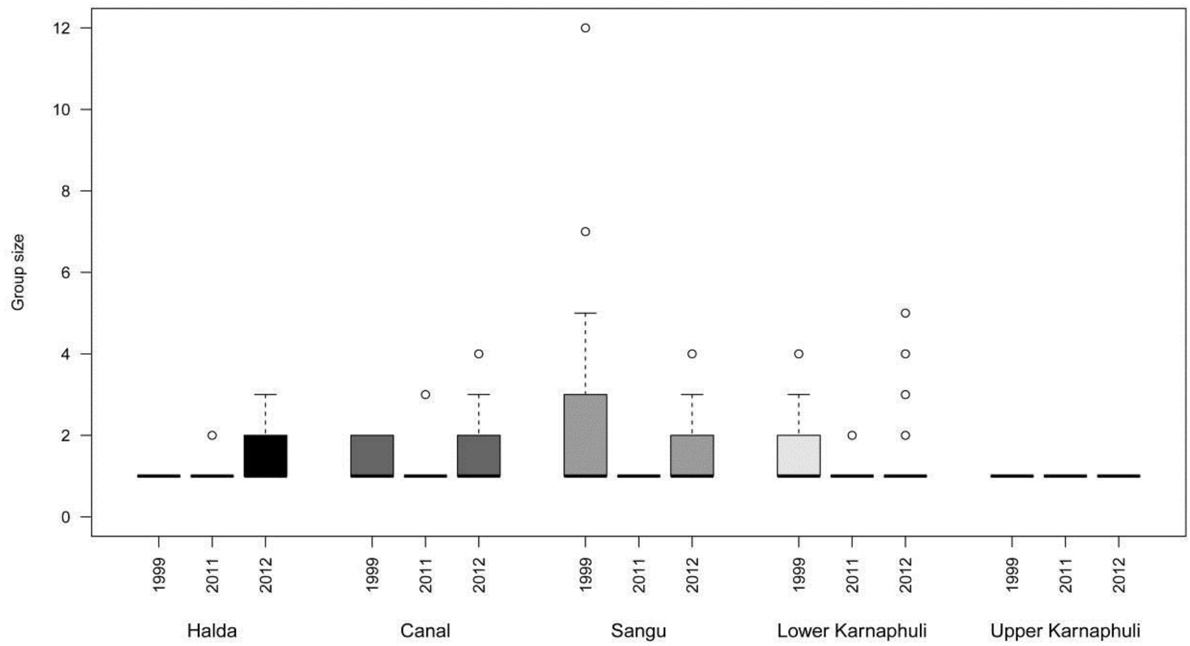

Figure 3.4: Distribution of group sizes across surveys (winter 1999, late autumn 2011 and winter 2012) and rivers. Note that the winter 2012 group size estimates are a mean of the one combined visual-acoustic survey and the two single observer-team visual surveys.

3.4.1. Winter 1999 abundance and long-term trends

During the winter 1999 survey a total of 114 dolphins were visually detected across all waterways (Table 3.4). Following correction for observer effort (Halda only), survey strip width (Lower Karnaphuli only) and acoustic effort (all waterways), abundance was estimated at 212 (CV = 6.3%, 95% CI: 189 - 241).

The comparison of abundance estimates from winter 1999 and winter 2012 revealed no significant overall long-term change in abundance for the entire study area (Figure 3.5). While there was evidence of a significant long-term increase in abundance in the Halda River, variability in the correction factors applied to the 1999 visual count created uncertainty in the trend. While no decline was detectable in the Upper Karnaphuli River due to sample size, the visual count data suggest that a decline may have occurred (six detections during winter 1999, and a single detection during the winter 2012 surveys).

The varying combination of correction factors altered the winter 1999 abundance estimate by up to 41 individuals (low abundance = 187, high abundance = 228). The majority of this variation was attributed to the uncertainty in the correction factors applied to the Lower Karnaphuli River that resulted in the estimate of abundance varying by 21 individuals (low abundance = 54; high abundance = 75). There was less variation in the overall estimate of abundance between the winter 2012 surveys (i.e. difference of 26 individuals, low abundance = 185; high abundance = 211), but the single observer team surveys were only corrected for acoustic effort, while the winter 1999 surveys of each river could be corrected for observer effort, strip width and acoustic effort.

As with the analysis of seasonal differences in abundance, it is unlikely that changes in abundance have been influenced by group size as mean group size has not changed between 1999 and 2012 (Figure 3.4). While the data indicate that there were some larger groups during the 1999 survey (Figure 3.4) this may be attributed to the fact that in the 1999 survey groups of individuals were defined over a larger spatial area (Table 3.1). Patterns of encounter rates between the rivers have remained relatively unchanged between 1999 and 2012 with the Halda, Upper Karnaphuli and Shikalbaha-Chandkhali Canal exhibiting lower encounter rates relative to the Lower Karnaphuli and Sangu (Table 3.4).

3.4.2. Coastal surveys

During the first coastal transect, a single group of two Ganges River dolphins was detected approximately 7.5 km from the mouth of the Karnaphuli River and 6 km from the mouth of the Sangu River at a salinity of 28 ppt (Figure 3.6). During the second transect, two groups of two and one single Ganges River dolphin were detected at salinities ranging from 28 ppt to 30 ppt and in close proximity to groups of Irrawaddy dolphins (*Orcaella brevirostris*). A total of 12 surfacings were recorded during the first transect, and 18 during the second transect. All sightings of Ganges River dolphins were identified by two experienced observers (i.e. carried out more than five surveys).

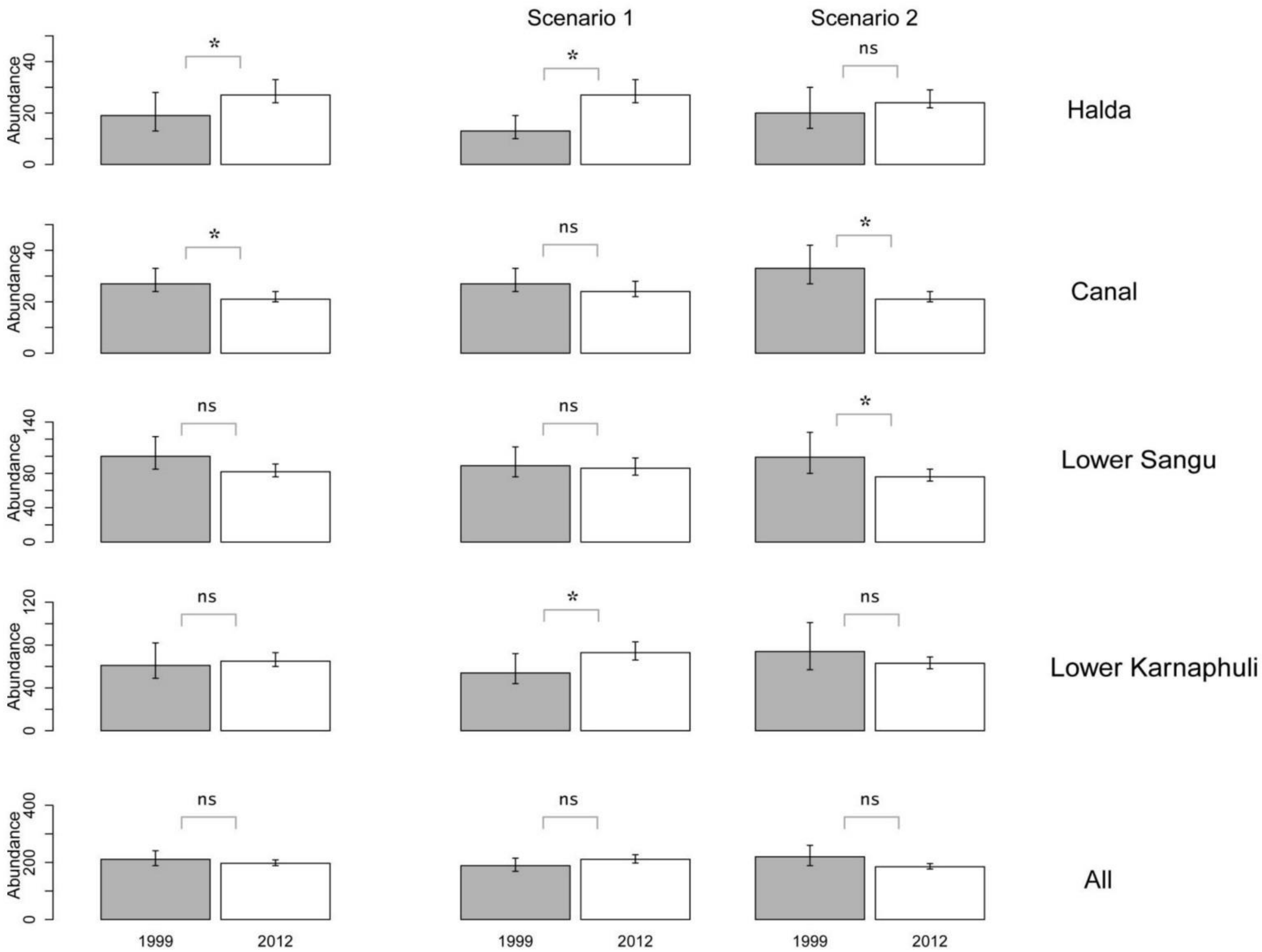

Figure 3.5: A comparison of long-term (winter 1999 to winter 2012) trends in the abundance of Ganges River dolphins in the Karnaphuli-Sangu rivers complex. The left hand image represents modelled abundance and trends. The right hand images represent the results of the sensitivity analysis under scenario 1 (lowest winter 1999 abundance estimate compared to the highest winter 2012 abundance estimate) and scenario 2 (highest winter 1999 abundance estimate compared to the lowest winter 2012 abundance estimate).

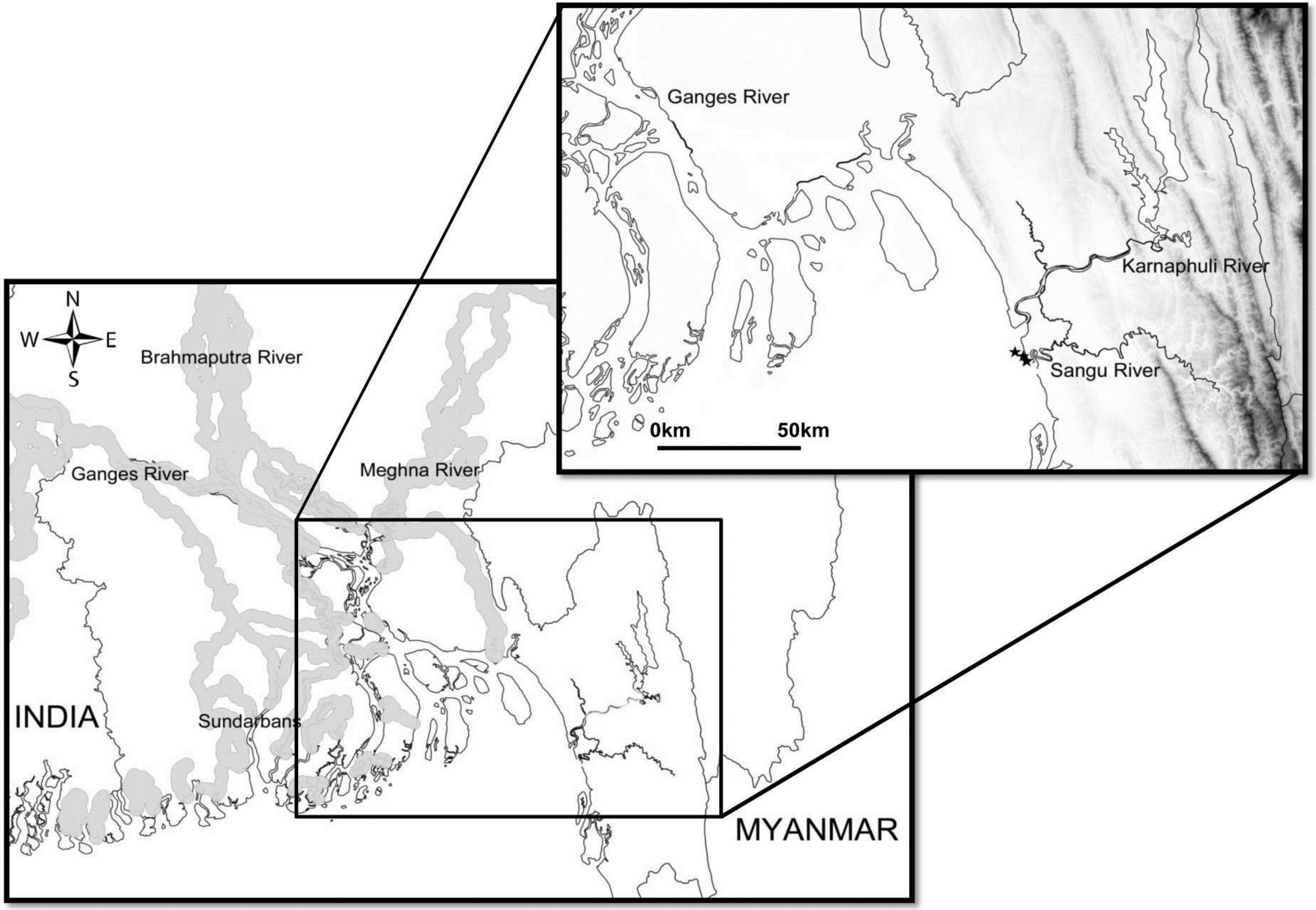

Figure 3.6: Location of Ganges River dolphin coastal sightings (black stars on inset map) during coastal transects between the Lower Karnaphuli River mouth and Sangu River mouth in winter 2012. The river channels shaded in grey indicate the known locations of Ganges River dolphin sightings during other surveys.

3.5. Discussion

3.5.1. Abundance

Most of the world's freshwater cetaceans are declining in abundance (e.g. Secchi and Wang, 2002; Huang *et al*., 2012; Beasley *et al*., 2013; Mintzer *et al*., 2013). Given the global lack of resources available for river dolphin conservation, identification of priority areas for attention is urgently needed. This study has identified a globally important abundance hotspot of Ganges River dolphins in southern Bangladesh. A mean of the three winter 2012 surveys, suggests there are approximately 197 Ganges River dolphins occupying the Karnaphuli-Sangu rivers complex with encounter rates among the highest yet recorded for this species. Encounter rates of 3.4 individuals per linear km (Braulik *et al*., 2012b) and 2.8 individuals per linear km (Choudhary *et al*., 2006) have been recorded elsewhere, though encounter rates of less than one individual per linear km are more common (Smith *et al*., 2006; Bashir *et al*., 2010b; Khatri *et al*., 2010; Singh and Rao, 2012).

Encounter rates were particularly high in the lower reaches of the Sangu River around the town of Gahira (i.e. 9 per linear km along a 4 km section). Reports by fishers and observations of the dolphins suggest that the high density of dolphins around Gahira might be related to local abundance of shrimp larvae. During the winter 2012 surveys, large numbers of shrimp larvae fishing gear (i.e. post-larval set-bag nets and pull nets; Ahmed and Troell, 2010) were seen in operation in the Gahira area, but with a complete absence of this gear type in any other waterway. Dolphins were observed displaying feeding behaviour (i.e. leaping and circular diving patterns; Sinha *et al*., 2010), supporting the hypothesis that this area is an important feeding ground (Ahmed, 2004).

Despite the low levels of human disturbance in the Upper Karnaphuli River, few dolphins were detected visually or acoustically. Recent bathymetric data from the Upper Karnaphuli River shows that river depth is typically less than 10 m, with a median depth of only 2.4 m in a 15 km section between the Karnaphuli Paper Mill and Rangunia Bridge (Institute of Water Modelling, 2009). In a recent study by Braulik *et al*. (2012), Indus River dolphins (*Platanista gangetica minor*) were found to avoid channels with a cross-sectional area of less than 700 m^2 and a depth of less than 1 m. The 15km stretch of the Upper Karnaphuli River has a median cross-sectional area of only 600 m^2. This shallow river stretch may pose a significant barrier to dispersal during the dry season.

3.5.2. *Seasonal migrations and population closure*

While dolphin movement may be restricted at particular times of the year, the results found evidence of significant seasonal movement. As all available riverine dolphin habitat was surveyed, it is concluded that there is late autumn migration of dolphins to outside of the river complex and into the Bay of Bengal, or across the Bay of Bengal and into other river systems. If the winter increase in abundance were attributed to detectability rather than a true change in abundance, then visual detectability for the late autumn 2011 survey would have to be about half that of the winter 2012 survey. A difference in detectability of this degree seems improbable given that factors that affect detectability were accounted for in the survey design, and so the difference between seasons likely reflects a genuine change in abundance. Furthermore, Ganges River dolphins are known to undergo seasonal changes in distribution and abundance in other parts of their range. During the monsoon season the density of dolphins occupying the main channel of the Ganges River declines as they follow migratory fish to their spawning grounds in smaller tributaries (Kasuya and Haque, 1972; Reeves and Brownell Jr, 1989; Shreshtha, 1989; Sinha and Sharma, 2003; Kelkar *et al*., 2010). While there is no empirical evidence of the dolphin subpopulation occupying the Karnaphuli-Sangu rivers complex migrating in response to fish migrations, the increase in winter dolphin abundance coincides with the migration of locally abundant Hilsa (*Tenualosa ilisha*) into these rivers (Rahman and Naevdal, 2000), suggesting that seasonal dolphin movements between marine and freshwater environments may be driven by similar spatial migrations of key prey species in this region.

The coastal sightings of dolphins not only provides support for the theory that dolphins are making seasonal movements into coastal waters, but that the Karnaphuli-Sangu rivers complex subpopulation may not be isolated. While migration between subpopulations was first proposed by Smith *et al*. (2001), no evidence has yet been found to support this theory. Furthermore, Smith *et al*. (2001) suggested that migrations would be likely to occur during the monsoon when the salinity in the Bay of Bengal is at its lowest. While surveys were not conducted during the monsoon, the sightings in coastal waters during the dry season when salinity is at its highest make a larger monsoon migration more plausible.

The occurrence of the Ganges River dolphins in coastal waters was surprising given the level of previous search effort in coastal waters, particularly around the Bangladesh Sundarbans. Numerous surveys of marine cetaceans have been carried out in the Bay of Bengal (i.e. four winter surveys in the Swatch of No Ground, Mansur *et al*., 2012; one winter survey of the Chittagong coast line, Smith *et al*., 2001) during which Ganges River dolphins have never been sighted. The absence of Ganges River dolphins from the coastal waters of the Sundarbans might be an artefact of competitive exclusion with marine delphinids (Whitmore Jr, 1994), such as the Indo-pacific Humpback dolphin and the Irrawaddy dolphin, that commonly occur in the region. While Irrawaddy dolphins were historically known from the lower reaches of the Sangu River (e.g. Ahmed, 2004), no sightings were made during recent surveys, or during the 6 month field season during which the research team made a number of trips along this river section. The absence of Irrawaddy dolphins may have allowed the Ganges River dolphin to expand its range further downstream and into coastal waters. Alternatively, if the coastal occurrence of Ganges River dolphins is a recent phenomenon this might indicate an ecological reversal, similar to that seen by the La Plata dolphin, whereby dolphins have been forced into coastal waters by declining food sources and habitat degradation (Cassens *et al*., 2000).

The sightings of Ganges River dolphins in coastal waters also indicates that the species is more tolerant of high salinities than previously supposed. Ganges River dolphins evolved from marine ancestors that are thought to have moved into freshwater environments during the Late Neogene (approximately 2.3 - 6 mya; Hamilton *et al*., 2001). It is expected that long-term adaptation to reduced osmoregulatory pressure in freshwater conditions would have reduced the capacity for osmoregulation in marine environments, which is evidenced by their unlobulated kidneys (Smith, 2002). However, two lines of evidence suggest that river dolphins may still use coastal waters. A recent study on the Yangtze River dolphin (Xu *et al*., 2013) found significant positive selection of genes involved in osmoregulation, suggesting a strong dependence on the ability to osmoregulate. Furthermore, anecdotal reports from both Chinese and Bangladeshi fishers have indicated that both the Yangtze and Ganges River dolphin can occupy marine waters (Zhou *et al*., 1977; E. Mahabub pers. comm. 2012).

3.5.3. Long-term trends

The current IUCN estimate of decline in the global population of South Asian river dolphins (i.e. Ganges River dolphins and Indus River dolphins) is based on proxy data using declines in extent of occurrence (Smith *et al*., 2004). I found no evidence of a long-term decline in abundance within the study area, though this finding must be taken in the context of uncertainty in the abundance estimates. The sensitivity analysis on the correction factors altered the 1999 and 2012 abundance estimates by up to 41 and 26 individuals respectively revealing a potentially small decline in abundance but at a rate that it is not yet detectable.

While the data suggest there has been no significant long-term change in abundance, the results indicate a possible decline in overall range within the southern rivers region. A decline in the extent of occurrence of Ganges River dolphins has already been documented for the Karnaphuli-Sangu rivers complex following the construction of Kaptai Dam in 1962, which extirpated dolphins from what is now Kaptai Lake (Smith *et al*., 2001). While it was not possible to identify an abundance trend in the Upper Karnaphuli, the number of visual detections declined from six to one between 1999 and 2012. Similarly, in the Sangu River between Chandanaish and Dohazari no dolphins were detected during the 2011, 2012 or pilot surveys; however, three dolphins were detected in this section during the 1999 survey. The decline in range extent within the Sangu River is likely a result of declining river depth that is further exacerbated by a recent ban on dredging in the Sangu; historically (i.e. 1999) the river section between Chandanaish and Dohazari was passable by motorised boat. Combined with increasing saltwater intrusion in the coastal rivers of Bangladesh (Rahman *et al*., 2000), these factors alone may lead to extirpation of dolphins in the Sangu even in the absence of all other threats.

The data suggest there has potentially been a significant increase in abundance in the Halda River. Over the 13-year period between surveys, an increase in abundance was observed at a mean annual rate of 4.1%. While the increase in long-term dolphin abundance in the Halda River is suggestive of a positive effect of a year-round fishing ban imposed in 2007 (for the preservation of three commercially important Indian carp species [Ruhi, *Labeo rohita*; Katla, *Catla catla;* Mrigal, *Cirrhinus cirrhosis*]), this may also simply reflect a shift in dolphin distribution between rivers in relation to prey availability.

3.5.4. Implications for conservation

Given the relatively low number of dolphins occupying the Karnaphuli-Sangu rivers complex and the possibility of a declining trend, confirming the direction and magnitude of the abundance trend in the shortest time frame possible is of critical importance. While our best estimate suggests that abundance has remained stable over time, this may be the result of immigration (i.e. the population may be a sink where the level of immigration is equal to mortality). A net gain of individuals is possibly driven by unstable population dynamics in surrounding river systems, or particularly favourable habitat conditions within the Karnaphuli-Sangu rivers complex. While declines in fish abundance have been documented in both the Halda and Karnaphuli (Ali Azadi and Arshad-ul-Alam, 2012), the Halda is a nationally important river in terms of fish abundance and is the only natural spawning site in the world for three commercially important Indian carp species (Ruhi, *Labeo rohita*; Katla, *Catla catla;* Mrigal, *Cirrhinus cirrhosus*), the seed stock of which support carp fisheries across the country.

At present there are no measures in place for the conservation of the Ganges River dolphin subpopulation occupying the Karnaphuli-Sangu rivers complex. Smith *et al*. (2001) proposed that a protected area be established in the Sangu River based on the high density of dolphins observed in this area relative to other waterways. There is increasing evidence that protected areas can be an effective tool for the preservation of marine mammal populations (Hooker and Gerber, 2004; Gormley *et al*., 2012), but their effectiveness is reliant on careful selection of the spatial boundaries. For example, southern resident Killer whales (*Orcinus orca*) are most vulnerable to being struck by boats when feeding and so only require a protected area of seven square nautical miles at a prime feeding site in order to significantly reduce levels of mortality (Ashe *et al*., 2010). Similarly, the boundaries of a protected area may need to change over time to account for range shifts in the target species (Wilson *et al*., 2004; Sciberras *et al*., 2013). At present, little is known on the contribution of the main anthropogenic factors to overall mortality of Ganges River dolphins. Observations from the Sundarbans indicate that entanglement in fishing gear is likely to constitute a significant source of mortality (Mahabub *et al*., 2012). During this study, dolphins were observed feeding in close proximity to shrimp nets in the Gahira meander of the Sangu River. A protected area in the Gahira meander may prove effective at reducing bycatch-related mortality if dolphins are in fact vulnerable to entanglement in this gear type. However, it may prove ineffective if the majority of mortality occurs outside of the Sangu River. A comparable problem was faced by *in situ* reserves established in the main Yangtze River channel for Yangtze River dolphins, which were relatively mobile species that moved in and out of these areas, thus diminishing the usefulness of the reserves (Turvey *et al*., 2010a). Protected area design for the Karnaphuli-Sangu rivers complex would benefit from further research into spatial and temporal patterns of both dolphin movements and the causal factors of mortality events.

3.5.5. Future monitoring schemes

The sightings of dolphins in coastal waters has potentially significant implications for management of the Karnaphuli-Sangu rivers complex population. While the results presented here indicate that the salinity in the Bay of Bengal is not as much of an ecological barrier to dispersal as previously thought (Ahmed, 2000), the results are not conclusive evidence that dolphins move between the Ganges-Meghna-Brahmaputra rivers complex, the Sundarbans and the Karnaphuli-Sangu rivers complex. However, evidence of the dolphin’s ability to tolerate coastal waters requires that future monitoring schemes focus on surveys of both the river system and coastal waters across multiple seasons. Expanding survey coverage to coastal waters is necessary for two reasons: 1) to determine whether there is a significant population in coastal waters and therefore whether abundance has been significantly underestimated; and 2) if seasonal changes are detected in the river system, to assess whether dolphins are simply migrating into the Bay of Bengal or moving elsewhere (i.e. other river systems). The continued use of the combined visual-acoustic method not only offers advantages in terms of comparable future estimates of abundance and long-term costs (see chapter two), but should improve overall detectability particularly during times of adverse sighting conditions that may be associated with monitoring in months outside of the dry season. However, given the potential analytical barriers to continued use of this method (see chapter two), it would be useful to carry out a comparison of the relative advantages of the methods that do account for detectability (i.e. double observer-team visual method, the tandem vessel visual survey method and the combined visual-acoustic method) in terms of the accuracy and precision of the abundance estimates they produce.

While there are advantages to the use of the combined visual-acoustic method in rivers, the presence of multiple small cetacean species in the neighbouring coastal waters (i.e. Irrawaddy dolphins; Indo-pacific finless porpoises, *Neophocaena phocaenoides;* Indo-Pacific humpback dolphins, *Sousa chinensis;* Pantropical spotted dolphins, *Stenella attenuata;* Spinner dolphins, *Stenella longirostris*; and Indo-pacific bottlenose dolphins, *Tursiops aduncus*) precludes the use of the hydrophone array used here given the issues with discriminating species based on click train patterns. Distance sampling likely represents the most robust method for coastal monitoring providing assumptions can be met.

3.5.6. Conclusions

Evidence from the seasonal difference analysis and sightings in coastal waters, highlight an important consideration for future surveys: are Ganges River dolphins confined to the coastal waters immediately surrounding the Karnaphuli and Sangu rivers, or is there connectivity with the dolphin subpopulation in the Ganges-Meghna-Brahmaputra rivers complex? Connectivity between subpopulations has important implications for interpretation of long-term trends and spatial management. While the small number of coastal sightings, suggest the coastal subpopulation is small, I would recommend re-defining the spatial coverage of future surveys to include the coastal waters around the Chittagong coastline. Sea-level rise and salt-water intrusion pose significant threats to isolated coastal populations of freshwater-dependent cetaceans emphasising the need and urgency for regular, standardised monitoring.

Chapter 4. Can local informants detect trends in the abundance of Ganges River dolphins?

One of the many logistical constraints associated with interview surveys

4.1. Abstract

Resource limitations have led to comparatively less monitoring of threatened species in developing countries. One relatively inexpensive approach that has received considerable interest is the use of interviews with local informants. Interviews can yield rapid socioeconomic and ecological data over a wide geographic range and in areas where data from standard ecological surveys would otherwise be absent. However, a lack of studies validating informant data mean there is still considerable uncertainty in its efficacy as a tool for monitoring population trends. Using abundance trends collected from boat-based surveys, I investigated whether local informants were able to detect seasonal differences and long-term trends in the abundance of Ganges River dolphins (*Platanista gangetica gangetica*), and the information they use to infer trends. While there was poor agreement between the two methods, a range of cognitive biases were identified that are likely to have influenced recall and highlight the need for further research. In particular, a decline in the

economic importance and numbers of dolphins may have led to ‘memory decay’ and ‘shifting baseline syndrome’. Local informant data did however prove a useful source of information at identifying potentially significant threats to river dolphins. Additionally, informants reported temporal changes in the spatial distribution of dolphins in the monsoon, a time of year when standard ecological surveys are limited by poor weather conditions. While there are a range of biases associated with collecting and interpreting informant data, future research needs to focus on developing a robust framework for handling these biases given the potential utility of interviews as a low-cost tool for studying poorly known species.

4.2. Introduction

Conservation requires robust information on species population trends over time for assessing the effectiveness of conservation measures (Stem *et al*., 2005) and the impact of threats (Rodrigues *et al*., 2006). Availability of data on the status and trends of animal populations is biased towards economically-important and charismatic species, and species located in developed countries (Nee, 2004) where comparatively greater resources are available for monitoring (Danielsen, Burgess and Balmford, 2005). This lack of resources has resulted in a search for low-cost alternatives to standard monitoring data. One approach which has received significant attention is the use of interviews with local informants to collect data on perceptions and knowledge of the local environment. There has been an increased recognition that interviews with local informants can provide potentially useful information for evaluating population trends (e.g. Anadón *et al*. 2009) and quantifying harvest levels (e.g. Gavin & Anderson 2005; Jones *et al*. 2008; Lozano-Montes *et al*. 2008; Rist *et al*. 2010). Interviews can yield rapid socioeconomic and ecological data over a wide geographic range and at low-cost (Turvey *et al*., 2014; White *et al*., 2005; Anadón *et al*., 2009; Turvey *et al*., 2013).

Interviews have been used for studying a variety of ecological subjects, including: species threats (Turvey *et al*., 2014) species occurrence (Meijaard *et al*., 2011), abundance and population trends (Daw, Robinson and Graham, 2011; Turvey *et al*., 2012, 2013; López *et al*., 2003; Lozano-Montes, Pitcher and Haggan, 2008; Anadón *et al*., 2009) and harvest levels (Jones *et al*., 2008; Moore *et al*., 2010). However, studies have demonstrated a range of biases that can impact informant recall and inference thereby affecting the accuracy of estimates (O’Donnell *et al*. 2010; Daw 2010; Moore *et al*. 2010; Table 4.1). During recall, informants employ a number of ‘shortcuts’ or cognitive heuristics (Tversky and Kahneman, 1973).

Table Error! No text of specified style in document.**.1**: Summary of the common biases that affect recall accuracy, and the methods that can be used for handling these biases.

Bias	Effect on inference	Recommendations for handling bias
Recall period	Accuracy of quantitative estimates may decline over longer recall periods (Bradburn, Rips and Shevell, 1987).	**Memory aids** – Recall of events from particular time periods can be aided using locally memorable events to define a time point, e.g. the year of a particular natural disaster or a local election. Furthermore, details of more recent events may aid remembrance of past events (Moore *et al*., 2010). In the study by Anadón *et al*. (2009), researchers found that starting interviews with questions on shepherds' daily behaviour improved the accuracy of tortoise abundance estimates later in the interviews (J.D. Anadón pers. comm. 2011). There is evidence that repeated attempts to recall past events can bring to light relevant new material, even after nine retrieval sessions of one hour each (Williams and Hollan, 1981). **Limit recall period** – Examples of recommended recall time periods include: three months (Hiett and Worrall, 1977), two months (Ghosh, 1978), and one month (Gems, Ghosh, & Hitlin, 1982). Tarrant *et al*., (1993) recommend a recall period of two weeks if obtaining estimates of fishing effort.
Species type	Rare species may be recalled with greater accuracy than common species (Rist *et al*. 2010). Economically and/or culturally important species may be recalled with greater accuracy than less important species (Lozano-Montes *et al*. 2008). Information about animals may be recalled more accurately than information about plants, a phenomenon termed 'plant blindness' (Gavin & Anderson 2005; Schussler & Olzak 2008).	**Document cultural and economic importance of a specie**s – be aware of the potential for recall errors with common species, and species of little interest to local communities.
Frequency of interaction	High variability in encounter rates and catch rates create noise and decrease the accuracy of response.	**Document variability** – Inter-annual variation in catch estimates and the effect of averaging catch statistics can be minimised by asking respondents to report catch on 'good', 'normal' and 'poor' catch days (Daw, Robinson, & Graham, 2011).
Misidentification	Identification-related errors can occur due to misidentification of a particular species, fishing gear-type, or location.	**Flash cards** – Picture cards depicting the species of interest, and other similar looking species, can be used to determine whether the informant can correctly identify the species and distinguish it from other local species (Meijaard *et al*., 2011). Furthermore, including pictures of species that do not occur in the study are can be used as a means to test informant reliability (i.e. informants who report catching these species, Moore *et al*., 2010).
Harvest effort	A change in harvesting effort over time may affect catch-per-unit-effort (CPUE) and therefore invalidate CPUE as an index of abundance.	**Document effort** – Temporal changes in effort may be accounted for by asking informants to recall 'high', 'low' and 'average' effort at varying time points, although this may be problematic across longer time periods (Daw, Robinson and Graham, 2011).

Shifting baseline syndrome	Declining trends may be underestimated as a result of generational amnesia and/or personal amnesia (Pauly 1995; Sáenz-Arroyo *et al*. 2005; Turvey *et al*. 2010a).	**Representative sample** – Ensure the interview sample accounts for variable levels of knowledge across different age groups or other demographic groups, and test to see if there is a significant difference in informant responses between these groups.
Social desirability bias	Informants intentionally over- or underestimate harvest or level of engagement in an activity because of the perceived status associated with a particular answer (Chase & Harada, 1984; Connelly & Brown, 1995; Lunn & Dearden, 2006). Reluctance to discuss, or downward biasing of illegal behaviours, may arise through perceived negative personal consequences (Tourangeau and Yan, 2007). In contrast, upwardly biasing harvest effort or harvest levels may occur to improve social positioning (Sheil and Wunder, 2002), or attract outside interest e.g. investment opportunities (Gomm, 2004).	**Triangulation** – An inferior form of validation that seeks to verify a piece of information from multiple research perspectives. Attempts at verification might be carried out using the same method or multiple methods (Flick, 1992) **Indirect questioning (i.e. Randomised Response Technique [RRT] or Nominative Technique [NT])** – Can reduce the bias of personal opinions by asking respondents to answer structured questions from the perspective of another person (Fisher, 1993). Examples of indirect questioning techniques include the nominative technique (Miller, 1985) and the randomised response technique (RRT) (Warner, 1965). The RRT method has been used to quantify illegal harvest of bushmeat (Razafimanahaka *et al*., 2012; Nuno *et al*., 2013) and assess rule-breaking behaviour (St. John *et al*., 2010).
Questionnaire structure and design	Decline in the accuracy of recalled information when too many questions are asked within a limited time period that informants are willing to devote to a survey.	**Interview length** – Relatively short (<30 min) closed-question surveys are recommended for collecting quantifiable or factual information (Huntington, 2000; White *et al*., 2005). Interview timing varies from 10 minutes (e.g. Daw *et al*. 2011) to all day (e.g. Anadón *et al*. 2009). Both short and long interviews have obvious drawbacks. Short interviews may not allow sufficient time to develop a rapport with the informant and put them at ease before questioning on sensitive topics. However, long interviews may bias results as respondents become bored of the interview (Bernard, 2006). **Questionnaire format –** A closed question format is generally recommended when the goal is to obtain quantitative data (White *et al*., 2005; Bernard, 2006; Newing, 2011)**.**
Misinterpretation	Questions may be misinterpreted where the researcher fails to use locally-appropriate terminology.	**Locally appropriate terminology** – A pilot study should be used to trial the questionnaire, check informant understanding of the questions, and gather data on locally-appropriate terminology and units of measurement (Newing, 2011). **Simple format** – A simple question-and-answer format minimizes possible biases caused by misinterpretation by respondents or researchers and therefore maximizes the accuracy of data (White *et al*., 2005).

Positive, rare and emotive events may be recalled with greater ease and frequency, exerting a greater influence on people's perceptions of historical conditions and thus biasing quantitative estimates (Bradburn, Rips and Shevell, 1987; Tregenza, 1992). Relatively unimportant events (e.g. capture of non-target species, or culturally and economically unimportant species) may instead be prone to higher levels of memory-related error (Fowler, 2002; Rist *et al*., 2010). Temporal changes in harvest effort (or any other factor that alters interaction frequency) may alter average catch size of target species, leading informants to conclude there has been a change in abundance (Daw, 2010; Daw, Robinson and Graham, 2011). Declining trends may be underestimated as a result of generational amnesia and/or personal amnesia, a phenomenon known as 'shifting baseline syndrome' (Pauly, 1995; Sáenz-Arroyo *et al*., 2005; Turvey *et al*., 2010b). Furthermore, informants may consciously over- or underestimate harvest or level of engagement in an activity because of the perceived status associated with a particular answer (termed social desirability bias). The lack of a standardised methodology for handling these biases means that there are concerns regarding the accuracy of local informant data (Moore *et al*., 2010).

Questionnaire design and structure, and interviewer translation and interpretation represent additional sources of error in questionnaire-based surveys (Sudman and Bradburn, 1974; McGorry, 2000; White *et al*., 2005; Lunn and Dearden, 2006; Moore *et al*., 2010; Newing, 2011). Misinterpretation of questions due to ambiguous wording (Moore *et al*., 2010), lengthy interview timing (Bernard, 2006), and poor questionnaire structure (Newing, 2011) can all affect the accuracy of informant responses. Poor documentation of survey methodology and potential biases has impeded efforts to develop standardised methodologies for carrying out questionnaire-based surveys (Moore *et al*., 2010). Given the potential utility of interview surveys in providing rapid, low-cost data in areas where standard ecological surveys may not be feasible, there is a need for studies validating informant data (Jones *et al*., 2008). Previous attempts to validate local informant data with independently-derived data, have shown good agreement (Jones *et al*., 2008; Rist *et al*., 2010; Anadón *et al*., 2009), and poor agreement between methods (Daw, Robinson, & Graham, 2011; Gavin & Anderson, 2005; Lozano-Montes, Pitcher, & Haggan, 2008; Lunn & Dearden, 2006). However, the paucity of studies validating local informant data with independently-derived data means there is still insufficient information from which to develop methods for handling biases.

Freshwater cetaceans are one of the most threatened groups of mammals on earth (Reeves, Smith and Kasuya, 2000). Despite their highly threatened status, relatively little is known with regard to population trends. Most of the world's freshwater cetacean species occur in developing countries and occupy broad geographic ranges, and so local informants may prove an important tool for detecting trends and identifying threats. Freshwater cetaceans also have a range of both cultural and economic values to local fisher communities (e.g. cooperative fishing in which dolphins herd fish into fishing nets in return for food, D' Lima *et al*. 2013; dolphin oil used as a fishing bait and for medicinal purposes, Reeves *et al*. 2000; Sinha 2002), and so may have generated a potentially large source of knowledge among these communities. Previous studies have found that fishers can provide information on both the status and extinction drivers in freshwater cetaceans (Turvey *et al*., 2013; Braulik *et al*., 2014b). In this study, I investigate whether local informants can detect seasonal differences and long-term (i.e. 13 year time period) trends in abundance in a subpopulation of Ganges River dolphins (*Platanista gangetica gangetica*) by comparing local informant data to data from boat-based surveys. I also investigate how informants infer abundance trends in river dolphins, and discuss the likely biases that influence these inferences.

4.3. Methods

4.3.1. Data collection

4.3.1.1. Study area

The study was conducted in the Karnaphuli-Sangu rivers complex of southern Bangladesh. The Karnaphuli-Sangu rivers complex covers 667 linear km, of which 159 km is occupied by the Ganges River dolphin. The two largest rivers (Karnaphuli and Sangu) pass through the Chittagong Hill Tracts (CHT), a hill range that extends from the eastern Himalayas and runs along the border of Bangladesh, India and Myanmar (Figure 4.1). In 1962, Kaptai Dam was constructed on the Karnaphuli River approximately 48 kilometres upstream from Chittagong. The construction of Kaptai Dam is believed to have resulted in the extirpation of Ganges River dolphins from upstream habitat (Ahmed, 2000; Smith *et al*., 2001). Moreover, the construction of Kaptai Dam resulted in the flooding of 22,000 ha of land in the Chittagong Hill Tracts forcing 100,000 people to migrate to higher ground (Karmakar *et al*., 2011). Subsequently there has been significant deforestation in the CHT resulting in sedimentation of both the Sangu and Karnaphuli rivers. Similarly, ox-bow cutting in the Halda River has resulted in sedimentation and subsequent degradation of the only national natural spawning ground for carp (i.e. *Catla catla, Cirrhinus mrigala*, *Labeo calbasu* and *L*. *rohita*). The waterways vary considerably in terms of their levels of anthropogenic impacts: the lower reach of the Karnaphuli River (i.e. below Kalurghat Bridge and hereafter referred to as the Lower Karnaphuli River) is home to Chittagong Port, one of the world's largest ship-breaking yards, and approximately 80 commercial factories.

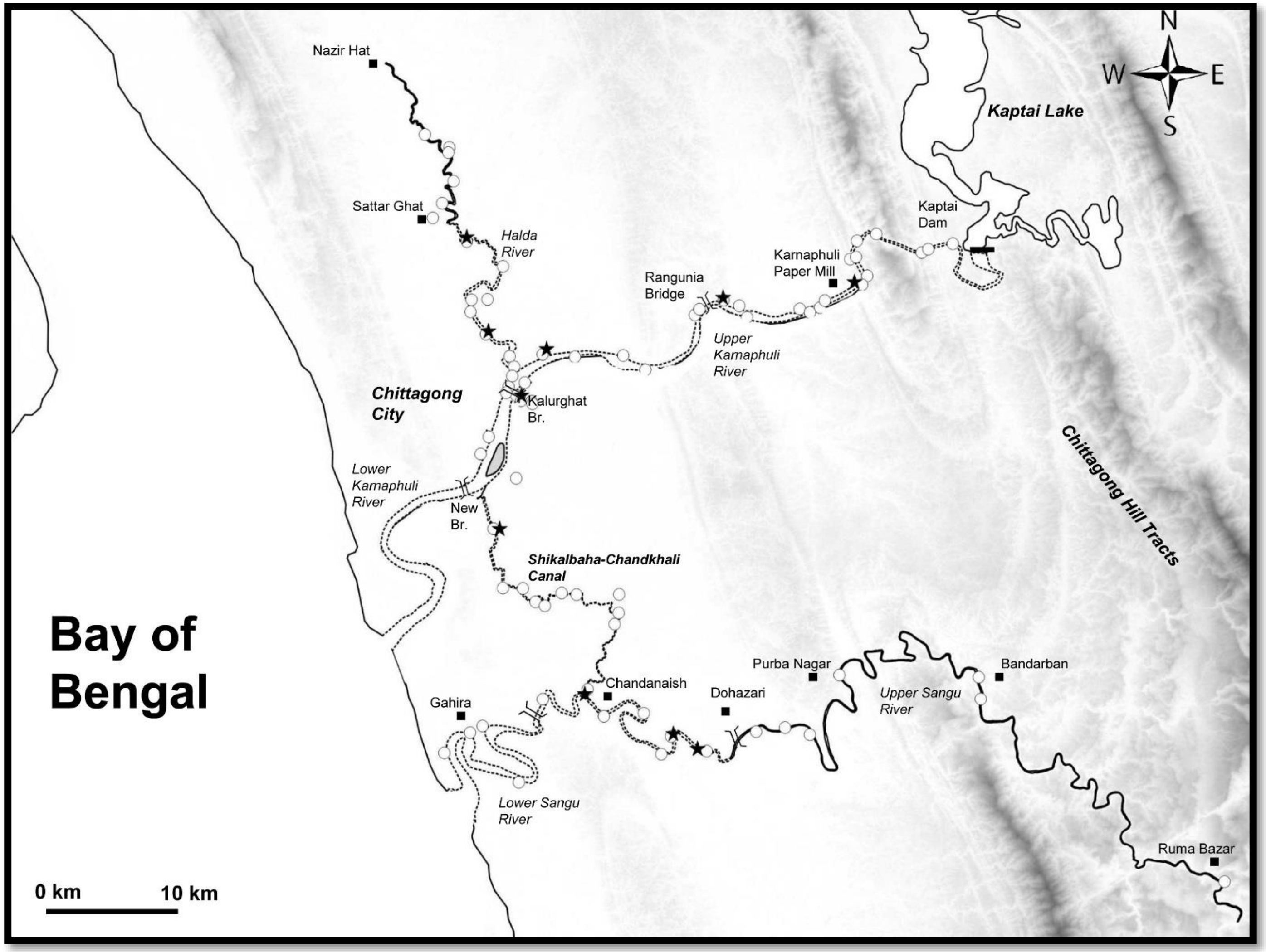

Figure 4.1: Pilot study settlements (black stars) and interview settlements (white circles) bordering waterways covered by the 1999, 2011 and 2012 boat-based surveys (dotted outline). Note the absence of interview settlements from the Lower Karnaphuli River due to the presence of Chittagong Port, ship-breaking yard, naval port and industrial zone.

However, the upper reach of the Karnaphuli River (i.e. above Kalurghat Bridge and hereafter referred to as the Upper Karnaphuli River) is relatively under-developed and surrounded by teak and tea plantations and smaller settlements. Similar to the Upper Karnaphuli River, the Sangu is relatively under-developed and much of the surrounding land south of Dohazari (referred to as the Lower Sangu River) is used for agricultural purposes. North of Dohazari (referred to as the Upper Sangu River) the river is unpassable by motorised vessel during the low water or winter season.

Interviews were carried out between October 2011 and February 2012 in settlements bordering all four waterways covered by the boat-based surveys described in chapter three. Both the boat-based survey and interview survey covered the entire range of Ganges River dolphins within the Karnaphuli-Sangu rivers complex. The interview survey was extended up to Ruma Bazar on the Upper Sangu River, and Nazir Hat on the Halda River where there are large populations of seasonal fishers that fish on the lower reaches of each river during the monsoon. Interviews were not conducted south of New Bridge on the Lower Karnaphuli River as there are few settlements in this area, and most of these are populated by Chittagong Port industry workers.

4.3.1.2. Informant selection

As the study aimed to collect informant knowledge of Ganges River dolphin trends in each of the waterways, and given the wider aims objectives of this research [i.e. studying bycatch patterns]) riverine fishers (hereafter simply referred to as fishers) were selected as appropriate informants.

4.3.1.3. Pilot survey

Prior to the main interview survey, a pilot survey was conducted in settlements across all four waterways (Figure 4.1). The pilot survey was used to develop a sampling protocol, test informant understanding of the questionnaire, provide training for interview teams, determine locally appropriate names for species, and create a list of geo-referenced place names and features (e.g. bridges, settlements, mosques, boat ports, sluice gates) that could be used as a reference guide for delineating fishing ranges.

The pilot study was also used to test informant understanding of the questionnaire and gather information on locally appropriate names. Questionnaire design was based on recommendations from Chambers (1992) and Bernard (2006) and comprised both closed and open-ended questions. All closed questions incorporated 'don't know' and 'other' options to minimise pressure to provide a response where informants had no true opinion (Krosnick *et al*., 2002) and allow for unforeseen responses (Moore *et al*., 2010). To minimise the effect of non-response or inaccurate responses due to tiredness (White *et al*., 2005; Moore *et al*., 2010), the questionnaire was designed to take no more than 30 minutes.

4.3.1.3.1. Developing a sampling design

The pilot survey was also used to develop a sampling protocol for the main interview survey. A random sampling protocol was attempted by randomly selecting both settlements and informant homes. Data on the location of each settlement in the study area was based on 2011 census data provided by the Bangladesh Center of Environmental and Geographic Information Services (CEGIS). The number of settlements was estimated in QGIS version 2.2.0 - Valmiera (QGIS Development Team, 2014) by applying a one kilometre buffer strip to each waterway and estimating the number of settlements that occur within, or intersect with, the boundaries of the buffer strip. It was assumed that fisher settlements are located within one kilometre of the river bank, as previous survey work carried out by a research team from Chittagong University found that fisher homes are typically within a few hundred metres of the river bank for ease of access. This assumption was validated during visits to pilot settlements, through informal discussions with local residents and village elders and visits to settlements up to four kilometres inland. Pilot surveys were undertaken in 10 settlements randomly selected from the 296 settlements within the buffer strip. If there were no fishers living in the randomly selected settlement then data collectors moved to the next closest settlement. Visits were made to a total of 36 settlements within the survey strip, of which only six were occupied by fishers. Assuming that a sixth of all settlements are occupied by fishers, then only 44 of the 296 settlements would contain fishers. Pilot surveys at each settlement revealed that the majority of fishers (n=41/46) operate in small, discrete areas (median = 4.5 linear km; SD: 7.2) of the river adjacent to their settlement, while the remainder may cover areas up to tens of kilometres. Similarly, random selection of fisher homes was attempted in three of the settlements, however, fishers were often found away from home (e.g. out fishing, at the local mosque for prayers, selling fish at markets, working in another occupation).

4.3.1.4. Sampling design for the interview survey

Given the logistical issues with obtaining a random sample of settlements and informants, it was decided that the aim of the main interview survey was to carry out at least 600 interviews distributed across every fisher settlement that could be located within the one km buffer strip to ensure coverage of all waterway sections. Informants were located for interview using one of two techniques: convenience sampling, whereby informants were selected for interview because they fit the informant selection criteria and were available at the time of site visits; and snowball sampling, whereby appropriate informants are interviewed and then asked to identify or suggest other informants for interview (Newing, 2011).

4.3.1.5. Interview survey

Interviews were carried out by three teams consisting of a translator who was responsible for carrying out the interview, and a native English speaker who was responsible for taking notes and asking additional questions if required. All interviews were conducted in Bangla (see Table S2 for Bangla version of the questionnaire). Back-translation was used to check informant understanding of the interview. Translators were encouraged to ask all questions in exactly the way they were detailed in the questionnaire, and to translate fisher responses in exactly the way they were conveyed. Translators were encouraged to inform the note-taker if they did not understand the informant's response. Interview teams were encouraged to maintain a neutral expression and neutral responses throughout the interviews so as not to bias informant responses (Bernard, 2006).

Consent was requested from each informant prior to interview. The objectives of the research were explained, and informants were assured that all responses were confidential, and that they could withdraw from the study at any time. Informants were asked a series of questions to assess perceptions and the economic importance of Ganges River dolphins (Appendix A, Table S1, Questions 30, 45-51); perceptions of both seasonal differences and long-term trends in dolphin abundance (Appendix A, Table S1, Questions 25, 28, 41); and the factor(s) responsible for these trends (Appendix A, Table S1, Questions 26, 29, 42). Additionally, informants were also asked to describe their age, fishing range (delineated by settlements, bridges, mosques etc.), number of days they fish each month, and whether there has been any change in their level of fishing effort (Appendix A, Table S1, Questions 1, 11, 12). Perceptions of seasonal differences were not asked of respondents in the Halda River or Shikalbaha-Chandkhali Canal, as these did not become a focus of the research until after boat-based surveys were completed in these areas.

We confirmed that informants could reliably identify Ganges River dolphins by asking fishers to identify three species from photographs: the Ganges River dolphin (locally known as *uchu mach*, *susu* or *shushuk*), and two locally abundant fish species, Phasha (*Setipinna phasa*) and Hilsa (*Tenualosa ilisha*). Where informants struggled with the identification of river dolphins, clues were given as to the behaviour and size of the animal. Correct identification of the river dolphin was further checked by asking informants to describe the habitats in which the dolphin is found (i.e. river, sea) and when they last saw one. Each fisher was assigned to one of three reliability categories: high (able to correctly identify all species); medium (able to identify river dolphin and one other species); and low (recognised only one species, identified only the fish species, or unable to identify any species). Only informants who scored 'high' and 'medium' were considered reliable, and data from the ‘low’ category were discarded.

4.3.2. *Data analysis*

4.3.2.1. *Can informants detect seasonal differences and long-term trends?*

Informants were assigned to a single location (i.e. Halda River, Shikalbaha-Chandkhali Canal, Lower Sangu River, Upper Sangu River, Lower Karnaphuli River, and Upper Karnaphuli River) based on the coverage of their fishing range. Informants whose fishing ranges covered multiple locations were excluded from the analysis (n=60). Each informant’s fishing range was plotted in QGIS using the database of geo-referenced place names to delineate the upper and lower limits of their fishing range. Informants whose fishing ranges covered multiple locations were excluded from subsequent analysis. For each location, the proportion of informants who perceived a particular trend (i.e. decreasing, no change and increasing) was estimated and compared to the seasonal differences and long-term trends from the boat-based surveys (see chapter three). To establish whether informant responses differed significantly from had they been generated randomly (i.e. 33% responses for each category), I calculated 95% binomial proportion confidence intervals around the trend with greatest number of responses. A statistically significant difference was concluded if the confidence interval did not include 33%.

Using the Kappa statistic (Cohen, 1960), I tested for the level of agreement between the informant and boat-based survey data where <0 = less than chance agreement, 0.01-0.20 = slight agreement, 0.21-0.40 = fair agreement, 0.41-0.60 = moderate agreement, 0.61-080 = substantial agreement, 0.81-0.99 = near-perfect agreement, and 1 = perfect agreement. Unfortunately, boat-based survey data on long-term trends in the Halda, Lower Karnaphuli, Lower Sangu and Shikalbaha-Chandkhali Canal were inconclusive due to the sensitivity of abundance estimates to different correction factors (see chapter three for details) and so could not be compared to informant data. There was also a mismatch in the time-frame over which long-term informant trends were recalled and boat trends were monitored (i.e. 2001 to 2011 versus 1999 to 2012). However, the size of this mismatch is small and so it was assumed that there were unlikely to be any significant changes in abundance during non-overlapping years.

4.3.2.2. *Reasons for seasonal differences and long-term trends*

Informant reasons for seasonal differences and long-term trends in abundance were categorised into common themes. Missing values were excluded from the analysis.

4.3.2.3. *How do informants infer there has been a change in abundance?*

A subset of informants (n=194) were asked a series of questions to determine how they inferred seasonal differences and long-term trends. Where an informant responded that there had been a decrease, no change or an increase in dolphin abundance, they were also asked how they determined this change: "*How do you know there has been an (insert reported trend) in the number of dolphins in the part of the river where you go fishing?*" Informant responses were categorised into common themes.

4.3.2.4. *Is there evidence of shifting baselines?*

T-tests were used to determine if there was a significant difference in the mean age of informants who reported that there had been no change or an increase in dolphin abundance, compared to those who reported a decrease.

4.4. Results

4.4.1. *Sampling design*

A total of 663 interviews were conducted in 74 settlements across the study area. Visa and safety restrictions prohibited access to settlements north of Kaptai Dam on the Upper Karnaphuli River. Informal discussions with the residents of Kaptai revealed that fishers living north of the dam typically fish on the lake only, and so it is unlikely that the survey design excluded a significant population of informants that fish on the study rivers.

All informants were male, ranging in age from 15 to 86 years (mean 44, SD = 14). The majority of informants were Hindu (91%, n = 602/663) while the rest were Muslim (9%, n = 61/663). Informants reported that women historically took part in fishing activities, albeit using hand nets or rod and line, but are now involved in fish sorting and preparation. Only eight fishers declined to give an interview, six of whom said they were too busy, and two who ran away.

Of the 663 interviewed informants, 83 were discarded either due to a 'low' reliability score or missing values, resulting in a final dataset of 580 interviews. All informants assigned a low reliability score failed to identify dolphins, the majority of whom (65%, n = 26/40) live and fish in the Upper Sangu around Bandarban and Ruma Bazar and so may have never encountered a dolphin.

4.4.2. Economic importance and perceptions of Ganges River dolphins

Other than five percent of informants (n = 30/580) who mentioned historical intentional hunting and killing of dolphins, I found no evidence of a significant fishery for the Ganges River dolphin. Four informants reported intentionally killing dolphins, but all other dolphins caught in fishing gear were accidental entanglements. Dolphin oil is still commonly used/known about among the communities of the study area: 25% (n = 143/580) of informants' families currently use dolphin oil for medicinal purposes (i.e. pain killer, burn treatment, diarrhoea treatment), for fattening livestock or as a machinery lubricant, and a further 36% (n = 208/580) had heard of people using dolphin oil but did not use it in their own family. However, I also found evidence to suggest that dolphin oil is declining in demand and economic importance: 32% (n = 185/580) of informants mentioned that they used to use it for treating varying ailments but no longer do so either because they no longer know where to get it (n=120) or they prefer to use conventional medicine (n=65). Of the informants who use dolphin oil, when asked where they buy it, 20% (n=28/143) reported that they or someone in their family has it, 6% (n=8/143) mentioned the name of a raw medicinal materials shop in Bakshirhat near Chittagong Port, 43% (n=61/143) mentioned that you just ask around to find someone, and 26% (n=37/143) said they didn't know. However, a large proportion of informants have received a bottle of oil for free (42%, n=61/143) from someone they know or a family member. The current price of dolphin oil is on average 1.88 taka ($0.02) per millilitre (range: 1-5 taka; SD=1.16), and those informants who sell it are able to sell on average 20 mls per month. While no data were collected on the average income of all interviewed informants, informal discussions with informants during the pilot survey revealed that fishers typically earn between 3,000 – 6,000 taka per month (equivalent to $38 - $77 per month), and so average monthly sales from dolphin oil are very low relative to other sources. Fourteen percent (n=4) of informants who claimed to have dolphin oil available to buy had extracted the oil over 18 years ago and commented that demand for the oil was very low nowadays as conventional medicine is now more readily available.

Dolphins were viewed favourably across the survey region, with 72% (n=417/580) of informants reporting that they like the dolphin. When asked why they like it, 91% (n=378/580) of informants responded that it is beautiful and enjoyable to watch, 3% (n=13/580) said that it causes no harm, 3% (n=13/580) said it brings the big fish to the river during the monsoon, 1% (n=5/580) said you can collect oil from it, and 2% (n=8/580) gave no reason. Of the 126 informants who didn't like the dolphin, 35% (n=44/580) of informants said it was because you can't do anything with it, 4% (n=5/580) said it's because they tear their nets, 4% (n=5/580) responded that they eat all the fish, 9% (n=12/580) said it smells bad, and the remaining 48% (n=60/580) provided no reason. Thirty seven informants were indifferent towards the dolphin.

4.4.3. Can informants detect seasonal differences and long-term trends?

Using only the data from locations with both local informant and boat-based survey data, there was poor agreement between the two data sources in terms of seasonal differences and long-term trends (Kappa statistic = 0.168, SE = 0.035, 95% CI = 0.010-0.24). The level of agreement improved to 'fair' when seasonal and long-term count data from the Upper Karnaphuli River were included (Kappa statistic = 0.260, SE = 0.027, 95% CI = 0.206-0.314), assuming that the boat-based surveys indicate no seasonal change in abundance and a long-term decline in abundance (Figure 4.2 and Figure 4.3).

Informant's perceptions of seasonal differences and long-term trends showed varying levels of consistency (Figure 4.2 and 4.3). However, the majority of informants perceived either an increase/ no change in seasonal abundance (Figure 4.2) and a long-term decline in abundance (Figure 4.3). Highest levels of consistency were observed for informant perceptions of seasonal trends in the Lower Sangu (increase 68%, 95% CI: 59% - 78%) and long-term trends in the Halda (decrease 82%, 95% CI: 69 - 95%) Upper Sangu (decrease 100%) and Upper Karnaphuli (decrease 65%, 95% CI: 58 - 71%). Unfortunately, it was not possible to carry out a comparison of data sources for this river section as boat-based surveys have never been carried out this far upstream due to shallow river depth. However, during the visit to the Upper Sangu River I met three fishers who informed me that historically (i.e. "*more than 20 years ago*"), between 6 - 10 river dolphins would migrate into this river section 8 km upstream from Bandarban during the monsoon when large fish migrated into the area for spawning.

The boat-based survey data suggests that the magnitude of change in abundance between time points may be an important factor determining the level of consistency between informant's perceptions of trends (Figure 4.2 and 4.3). The average magnitude of change in abundance was greatest for seasonal trends in the Lower Sangu (9.1 fold change), the Lower Karnaphuli (2.2 fold change), and the long-term trend the Upper Karnaphuli (-6.2 fold change), all of which exhibited greater (i.e. >57% selected one category) consistency among informant-perceived trends. In contrast, a low magnitude of change was observed in long-term abundance for the Lower Sangu (-1.2 fold change), the Lower Karnaphuli (-1.1 fold

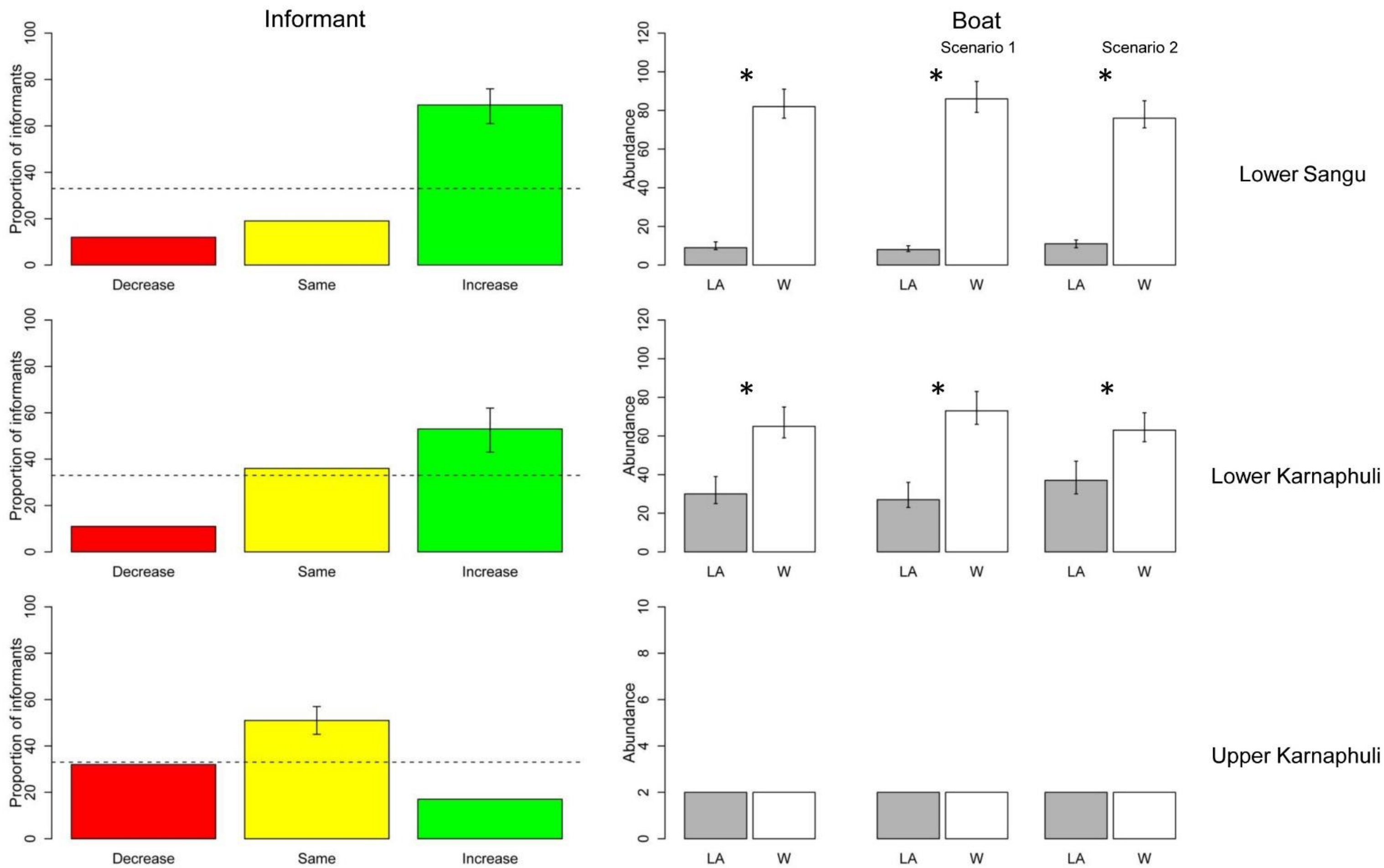

Figure 4.2: Seasonal differences (late-autumn 2011 [LA] to winter 2012 [W]) in Ganges River dolphin abundance based on informant interviews (left hand side image) and boat-based surveys (right-hand side image - based on figure 3.3). The dashed line on the informant data graphs indicates 33% i.e. the point at which informant reports might be considered random. The * on the boat-based survey graphs, indicates a significant difference between the two abundance estimates. Too few dolphin individuals were detected during boat surveys of the Upper Karnaphuli from which to determine whether there had been a statistically significant change in abundance and so abundance estimates are simply visual counts.

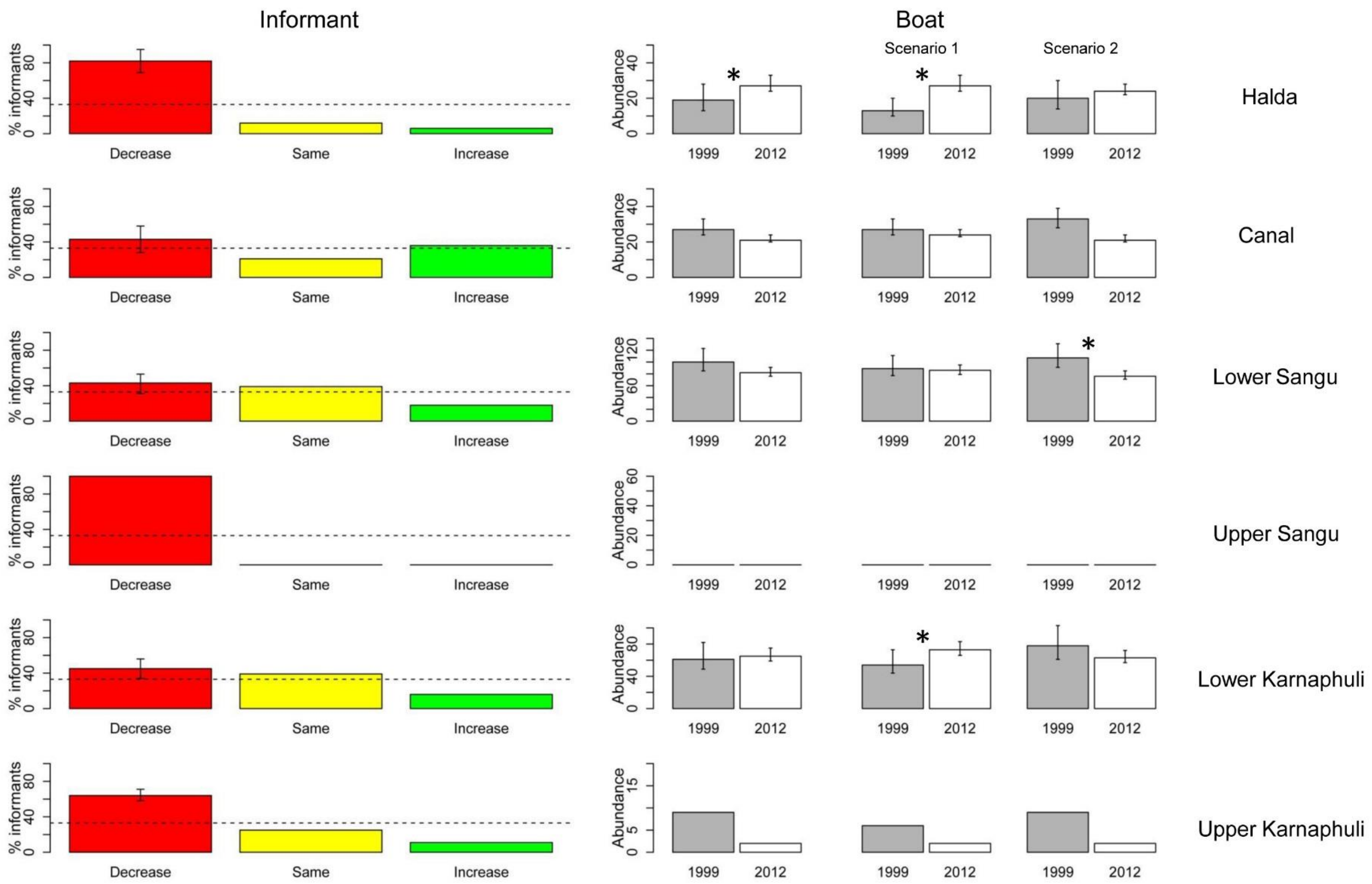

Figure 4.3: Long-term trends (1999 to 2012) in Ganges River dolphin abundance based on informant interviews (left hand side image - based on figure 3.5) and boat-based surveys (right-hand side image). The dashed line on the informant data graphs indicates 33% i.e. the point at which informant reports might be considered random. The * indicates a significant difference between the two abundance estimates. Too few dolphin individuals were detected during boat surveys of the Upper Karnaphuli from which to determine whether there had been a statistically significant change in abundance and so abundance estimates are simply visual counts.

change), and the canal (-1.3 fold change), all of which exhibited lower levels of consistency (i.e. <45% selected one category) among informants. In only two cases (long-term trends in the Lower Sangu River and Shikalbaha-Chandkhali Canal: Figure 4.3), was there no statistically significant difference in the category with the most responses from had it been generated randomly (i.e. confidence intervals overlapped 33%). While informant perceptions of long-term trends in the Lower Karnaphuli also showed a relatively low level of consistency (decrease - 45%, 95% CI: 34 - 56), the difference was deemed statistically significant.

4.4.4. Is there an annual peak in dolphin abundance in each waterway?

Informant reports of the seasonal differences in abundance in the each waterway suggest there is a migration of dolphins in the monsoon from the larger channels (i.e. Lower Karnaphuli and Lower Sangu) into smaller channels (i.e. Halda, Shikalbaha-Chandkhali Canal, Upper Karnaphuli and Upper Sangu; Figure 4.4), with dolphins returning to larger channels during the winter. This pattern is evidenced by the high consistency of informant reports (>70%) for a peak in dolphin abundance during the monsoon in small channels. There is greater variability in informant reports from the larger channels but the majority of informants suggest the peak is in the winter.

4.4.5. What are the reasons for the reported seasonal differences and long-term trends?

The majority of informants who perceived an increase in winter abundance relative to the late autumn, attributed it to dolphins migrating from the sea in response to prey availability, particularly in the Lower Sangu and Lower Karnaphuli (i.e. fish and shrimp; Table 4.2). In the Upper Karnaphuli, where the majority of informants perceived no change in seasonal abundance, the majority responded ‘don’t know’. Of the informants who perceived a decline in winter abundance relative to the late autumn, the most common response was ‘a decline in water depth’.

4.4.6. Is there an annual peak in dolphin abundance in each waterway?

Informant reports of the seasonal differences in abundance in the each waterway suggest there is a migration of dolphins in the monsoon from the larger channels (i.e. Lower Karnaphuli and Lower Sangu) into smaller channels (i.e. Halda, Shikalbaha-Chandkhali Canal, Upper Karnaphuli and Upper Sangu; Figure 4.4), with dolphins returning to larger channels during the winter. This pattern is evidenced by the high consistency of informant reports (>70%) for a peak in dolphin abundance during the monsoon in small channels.

There is greater variability in informant reports from the larger channels but the majority of informants suggest the peak is in the winter.

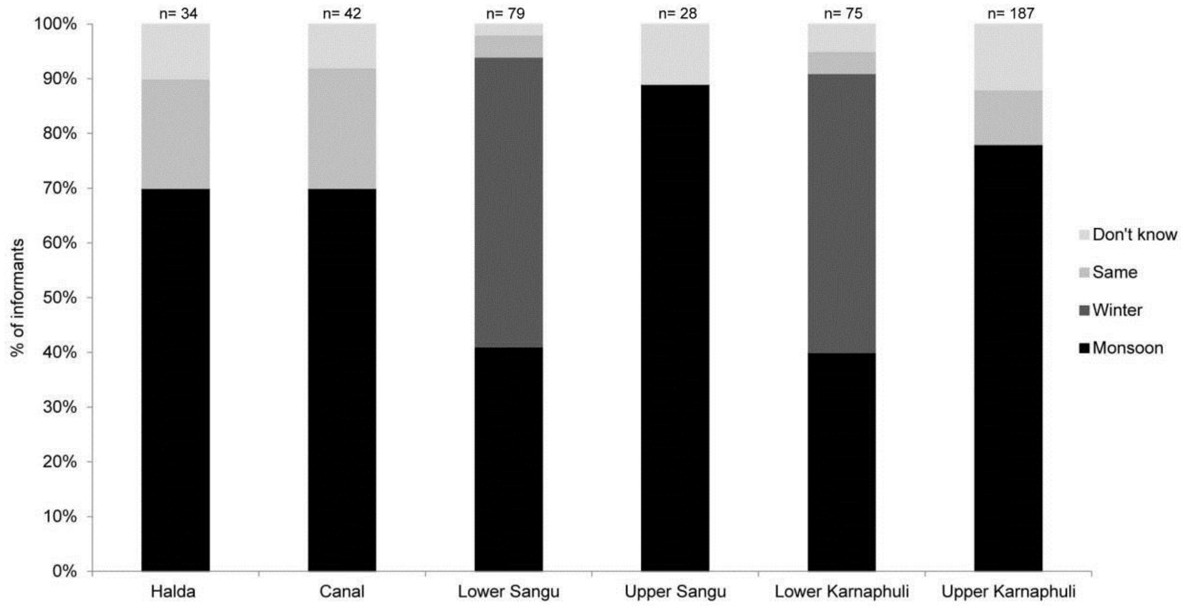

Figure 4.4: Peak dolphin abundance in each water way according to informant reports.

4.4.7. What are the reasons for the reported seasonal differences and long-term trends?

The majority of informants who perceived an increase in winter abundance relative to the late autumn, attributed it to dolphins migrating from the sea in response to prey availability, particularly in the Lower Sangu and Lower Karnaphuli (i.e. fish and shrimp; Table 4.2). In the Upper Karnaphuli, where the majority of informants perceived no change in seasonal abundance, the majority responded ‘don’t know’. Of the informants who perceived a decline in winter abundance relative to the late autumn, the most common response was ‘a decline in water depth’.

Informants provided a range of reasons for long-term declines in dolphin numbers (Table 4.3), but the most frequently reported reasons in the Halda, Lower Sangu, Upper Sangu and Shikalbaha-Chandkhali Canal were ‘declining river depth’ and ‘less food’. There was less consistency among informants of the Lower Karnaphuli River regarding the factors driving declines, while almost half of all Upper Karnaphuli informants attributing declines to ‘pollution from Karnaphuli Paper Mill’. Of the informants who mentioned Karnaphuli Paper Mill as a driver of decline, 10 informants mentioned that the release of untreated effluent sometimes results in large fish kills, and the waste burns their skin if they are bathing in the river at the time it is released so must also burn the dolphins. As with the seasonal differences, informants who perceived no change in long-term abundance provided no reason and simply responded ‘don’t know’. Of the informants who perceived long-term increases in abundance, ‘don’t die, just breed’ was the most common response in the Shikalbaha-Chandkhali Canal, Lower Sangu, and Upper Karnaphuli. When questioned further as to how they know the dolphins breed, informants from the Lower Sangu and Shikalbaha-Chandkhali Canal reported that they observe dolphins “give birth to young” during *Choitro* and *Boishakh* (i.e. March to May).

4.4.8. How do informants infer trends?

Of the informants who perceived long-term increases in abundance, ‘Don't die/ not killed, just breed so they must be increasing’ and ‘see more’ were the most commonly used lines of evidence for inferring trends (Table 4.4). Of the informants who perceived no change in abundance, ‘dolphins don’t die or get killed’ and ‘see it at the same rate’ were most commonly used to infer trends. Informants used a greater variety of factors for inferring declining trends, but ‘don’t see as many/ any at all’ and ‘don’t catch as many/ any at all’ were most often used. Other than informants based in the Shikalbaha-Chandkhali Canal and the Lower Sangu, the majority of informants used numbers of sightings or numbers of bycatch events to infer long-term trends.

4.4.9. Is there evidence of ‘shifting baselines’?

I found evidence of ‘shifting baseline syndrome’ in the Upper Karnaphuli River, where a significant difference (t =3.2560, d.f. = 201, p=0.0013) in the age of informants was detected between those who reported a decreasing trend (mean = 48 years, SD = 15, n = 131) and those who reported a stable/ increasing trend (mean = 41 years, SD = 14, n = 72). There was no evidence of shifting baselines in any of the other rivers.

Table 4.2: Informant perceptions of the principal drivers of seasonal differences (late-autumn and winter) in dolphin abundance. Some informants provided more than one response, hence why proportions can add up to more than 100%.

		Proportion of informants (number of responses)		
		Lower Sangu (n=89)	**Lower Karnaphuli (n=81)**	**Upper Karnaphuli (n=192)**
Increase	Come from the sea as more food (fish, shrimp) to eat	50% (45)	48% (39)	11% (22)
	More food to eat	22% (20)	-	4% (8)
	Come from the sea but don't know why	-	-	2% (3)
	Come to play	-	-	1% (2)
	Don't know	7% (6)	5% (4)	2% (4)
No change	Lots of fish for them to eat	-	11% (9)	4% (7)
	They breed	1% (1)	-	3% (6)
	Don't know	18% (16)	25% (20)	43% (82)
Decrease	Less water for them to swim	10% (9)	7% (6)	23% (45)
	Water is clear which they don't like	-	0	6% (12)
	Don't know	2% (2)	4% (3)	4% (8)

Table 4.3: Informant perceptions of the principal drivers of long-term trends (2001-2011) in dolphin abundance. Some informants provided more than one response, hence why proportions can add up to more than 100%.

		Proportion of fishers (number of responses)					
		Halda (n=37)	**Shikalbaha-Chandkhali (n=45)**	**Lower Sangu (n=89)**	**Upper Sangu (n=28)**	**Lower Karnaphuli (n=81)**	**Upper Karnaphuli (n=192)**
Increase	Don't die, just breed	-	16% (7)	11% (10)	-	4% (3)	6% (12)
	Increased water level	-	2% (1)	-	-	-	-
	People don't kill them	-	11% (5)	-	-	6% (5)	1% (2)
	More fish	3%(1)	-	-	-	-	-
	Don't know	3%(1)	-	11% (10)	-	5% (4)	3% (5)
No change	There is a fishing ban so they can't die	5% (2)	-	-	-	-	-
	People don't kill them	-	2% (1)	-	-	2% (2)	1% (2)
	Waste from Karnaphuli Paper Mill does not bother it	-	-	-	-	-	<1% (1)
	I see it always at the same rate	-	-	-	-	-	2% (4)
	Don't die, just breed	-	13% (6)	2% (2)	-	-	1% (2)
	Don't know	5% (2)	18% (8)	47% (42)	-	44% (36)	21% (40)
Decrease	Accidentally die in nets	3% (1)	2% (1)	2% (2)	-	2% (2)	<1% (1)
	People kill if caught in nets	-	-	3% (3)	-	-	<1% (1)
	Declining river depth	16% (6)	20% (9)	22% (20)	50% (14)	2% (2)	7% (14)
	Less food	41% (15)	9% (4)	8% (7)	50% (14)	4% (3)	10% (20)
	Too much noise from boats	-	-	-	-	-	2% (3)
	Pollution from Karnaphuli Paper Mill	-	-	-	-	2% (2)	30% (58)

	Pollution	-	4% (2)	-	-	4% (3)	<1% (1)
	Poison fishing	5% (2)	-	4% (4)	-	-	-
	Breed less	-	-	1% (1)	-	-	-
	Get too fat	-	-	-	-	4% (3)	-
	Don't know	24% (9)	18% (8)	4% (4)	-	25% (20)	16% (30)

Table 4.4: Responses from informants when asked how they knew whether an increase, no change or decrease had occurred in the long-term abundance of dolphins. Some informants provided more than one response, hence why proportions can add up to more than 100%.

		Proportion of fishers (number of responses)					
		Halda (n=22)	Shikalbaha-Chandkhali (n=20)	Lower Sangu (n=40)	Upper Sangu (n=9)	Lower Karnaphuli (n=38)	Upper Karnaphuli (n=65)
Increase	Don't die/ not killed, just breed so they must be increasing	-	20% (4)	30% (12)	-	10% (4)	11% (7)
	No fishing allowed since ban, so must be increasing	4% (1)	-	-	-	-	-
	I see more	-	-	15% (6)	-	8% (3)	5% (3)
	I catch more	-	5% (1)	5% (2)	-	-	-
	Don't know	-	5% (1)	-	-	10% (4)	3% (2)
No change	No fishing allowed since ban, so not killed	4% (1)	-	-	-	-	-
	Don't die or get killed	-	30% (6)	12% (5)	-	3% (1)	-
	I see it always at the same rate	-	10% (2)	20% (8)	-	5% (2)	3% (2)
	Don't know	14% (3)	-	5% (2)	-	39% (15)	3% (2)
Decrease	People kill so they must be decreasing	18% (4)	10% (2)	10% (4)	-	8% (3)	-
	Everything is decreasing, river is in bad condition	-	-	-	-	-	22% (14)
	Don't see as many/ any at all	27% (6)	15% (3)	-	-	21% (8)	5% (3)
	Don't catch as many	27% (6)	-	-	89% (8)	21% (8)	37% (24)
	My father told me	-	-	-	22% (2)	-	2% (1)
	Try to catch for oil, but cannot catch anymore	4% (1)	-	-	-	-	-
	Don't know	-	5% (1)	18% (7)	-	3% (1)	10% (6)

4.5. Discussion

4.5.1. Can informants detect seasonal differences and long-term trends?

Studies have demonstrated that local informants can accurately recall population trends and harvest estimates under certain conditions (Jones *et al*., 2008; Anadón *et al*., 2009; Rist *et al*., 2010; Lozano-Montes, Pitcher and Haggan, 2008). Local informant data on trends can act as an early warning system of population declines (Rochet *et al.,* 2008; Turvey *et al*., 2013), particularly where scientific methods may lack the power to detect short-term change. While in almost all cases, there was evidence that informants were not responding randomly to questions on seasonal differences and long-term trends, there was a poor level of agreement between the informant data and boat-based survey data regarding the direction of change. Unfortunately, the limited sample size prohibited investigation of the factors influencing informant perceptions, but a number of potential cognitive biases have been highlighted. Magnitude of ecological change may be an important factor determining informant detection (Aswani and Lauer, 2014), with larger changes typically being easier to detect (Rochet *et al*. 2008; Daw 2010; Aswani & Lauer 2014). Highest consistency was observed in informants of the Sangu and Upper Karnaphuli rivers (regarding the seasonal differences and long-term trends respectively), the two areas within the study region that exhibited the highest magnitude of change in dolphin numbers. While the low consistency among informants regarding the long-term trend in the Shikalbaha-Chandkhali Canal may be driven by a small overall magnitude of change, as detected by boat-based surveys, informants may have also been responding randomly. Alternately, low informant consistency may reflect the confounding effects of environmental variability: informants in this region reported large daily fluctuations in the abundance of dolphins in relation to tidal state, and frequently responded that it was difficult to determine the overall trend because of this variability. Significant daily variability in dolphin abundance was not reported at any of the other sites.

While the results indicate that in most cases informants were not simply responding randomly to questions on seasonal differences and long-term trends, there is still uncertainty as to whether this can be taken as evidence of informant's ability to detect changes in abundance or whether they are influenced by some other form of bias. For example, in the Upper Karnaphuli River 22% of informants based their perception of a long-term decline in dolphin abundance on the fact that the "river is in bad condition". Conversely, 30% of informants from the Lower Sangu River reported an increasing or stable long-term trend as they perceived that dolphins only breed and are not killed. While the data suggest that the majority of informants based their perceptions on some index of abundance, future studies could strengthen conclusions on informant's ability to detect trends by wording questions in a way that ensures all informants are recalling trends from the same index of abundance.

Ignoring potential temporal changes in harvest effort can bias the recall of harvest estimates or population trends (Lunn and Dearden, 2006; Daw, Robinson and Graham, 2011). My data suggest a possible role of effort on long-term trend perception in the Halda River that might explain the contradiction between the increasing trend as reported by the boat-based survey data and the decreasing trend reported by the majority of informants. Qualitative information suggests there has been a significant decline in fishing effort in the Halda River since implementation of a fishing ban in 2007. As the majority of informants used numbers of sightings and/ or caught dolphins to infer trends, a decline in fishing effort will have reduced the occurrence of both possibly leading informants to incorrectly perceive a decline in abundance. While declines in effort were reported at all locations, these were smaller in magnitude (i.e. typically in response to bans of only a month or two) relative to effort in the Halda River. The contradiction between methods highlights the importance of providing quantitative estimates of effort over time and incorporating these into sighting rates or harvest levels. Assuming the increase in abundance as detected by the boat-based surveys is accurate, then reliance on local informant data alone for allocating conservation resources may result in wasted effort in an area that does not require attention.

Experience and frequency of interaction with species can affect the recall of trends (Lozano-Montes, Pitcher and Haggan, 2008; Daw, Robinson and Graham, 2011). While I did not collect data on the frequency and nature of informant's interactions with the dolphin over time, informants may have differed in their ability to accurately recall trends depending on the gear they use. For example, some fishing gear require the informant to spend considerably longer periods of time on the river (e.g. gill nets), relative to others (e.g. long shore nets). Additionally, informants using gill nets are more likely to encounter dolphins due to an increased probability of dolphin bycatch occurring (see chapter five). Bycatch events may be considered memorable events as they bear an economic cost due to damage and/or loss of nets. Gear use and its effect on accuracy of recall might explain the particularly low level of agreement observed among fishers of the Shikalbaha-Chandkhali Canal where there were few informants using gill nets relative to other waterways (chapter five). Differences in gear types and therefore potentially the frequency of interaction with species, highlights the need for more careful consideration of appropriate informants when asking questions on species or events that may not be encountered/ occur frequently. The data also suggest that the nature of interactions can influence trend perception. Of the informants who perceived a long-term increase in abundance, a significant proportion reported that they only see dolphins breeding so they must be increasing in abundance. Furthermore, a large proportion also mentioned that dolphins are not killed by fishers and if they get caught in nets then they are released.

Knowledge on species of interest for conservation may be lost from local communities, particularly for species that are no longer valued for food or cultural reasons, or no longer frequently encountered (Pauly, 1995; Turvey *et al*. 2010a). The data presented here indicate a possible decline in the economic importance of dolphin products (i.e. oil and meat) for medicinal reasons, so much so that these products may be distributed for free amongst communities. I also found evidence of ‘shifting baseline syndrome’ in the Upper Karnaphuli River where there is a particularly low encounter rate of dolphins (0.02 individuals per km). While there were no informants who perceived a decreasing or stable trend in the Upper Sangu, there was evidence of generational knowledge transfer in this region, with younger informants reporting that their fathers had told them dolphins no longer occur in high numbers. This information may have been deemed culturally or economically important to pass on, as the informants in the Upper Sangu regarded the number of dolphins as an indicator of the size of the fish stock for that season. It is likely that with the loss of the older generation of informants, knowledge of the magnitude of the decline in dolphin numbers will be lost from the Upper Karnaphuli and Upper Sangu rivers.

4.5.2. Perceived trends

Interviews with local informants have proven a useful tool for assessing the causal mechanisms behind population trends (Leeney and Poncelet, 2013; Turvey *et al*., 2013; Ziembicki, Woinarski and Mackey, 2013; Turvey *et al*., 2014; Braulik *et al*., 2014b). For example, data from interviews has been used to understand how phases of the moon affect bumphead parrotfish (*Bolbometopon muricatum*) catch rates (Aswani and Hamilton, 2004), and how water management schemes have affected subpopulations of the Indus River dolphin (*Platanista gangetica minor*; Braulik *et al*. 2014b). Informant data presented here suggest there are potentially significant changes in the seasonal abundance of river dolphins across the study area with abundance peaking in smaller river channels during the monsoon, but moving back into larger channels during the winter. While there are no independent data to validate the monsoon changes in abundance, the findings broadly agree with observations of movement patterns from other areas in this species’ range. In the Ganges and Brahmaputra rivers, dolphins migrate from the main river channel to smaller tributaries in the monsoon (Wakid and Braulik, 2009; Sinha, Behera and Choudhary, 2010). Furthermore, studies of Hilsa fish migration in Bangladesh show that following spawning in the monsoon, *Jatka* (young Hilsa fish) migrate downstream into the river estuaries and coastal waters (Rahman and Naevdal, 2000; Bala *et al*., 2014). There is another smaller run of Hilsa fish into the river systems during the winter, though they do not migrate as far upstream (Rahman and Naevdal, 2000). This seasonal movement of river dolphins in the Karnaphuli-Sangu rivers complex has never been documented, but may have important implications for spatial management if these movements are associated with increased risk of mortality.

Interviews with local informants can yield a wealth of important information for species conservation, including the presence or absence of major extinction drivers (Turvey *et al*., 2007, 2012, 2013; Braulik *et al*., 2014b). However, there are a number of biases that can influence an informant's perception of how significant particular threats are to overall levels of mortality, including: media attention, visual clues and 'social norms'. In the Upper Karnaphuli River, the release of untreated effluent from Karnaphuli Paper Mill was perceived as the greatest threat to the dolphin. There are no data upon which to assess the significance of Karnaphuli Paper Mill as a threat to the dolphin; however, the data suggest this perception might be driven by media attention. Since the Karnaphuli Paper Mill was built in 1953 it has received considerable media attention regarding the environmental impact it has through dumping untreated effluent into the Upper Karnaphuli River. Furthermore, informants frequently used the same terminology when describing the negative components of the paper mill (i.e. "caustic acid", "sulphur gas", "black liquor"), all of which are terms frequently used in the local media. In contrast, few informants cited 'pollution' as a threat, possibly given the lack of visual clues on dead animals (Turvey *et al*., 2013). It might be expected then that threats such as intentional and accidental mortality would be cited with greater frequency given they are wide-spread and frequent (see chapter five). The fact these threats were mentioned by only 11 informants suggests that informants may not have been comfortable discussing this source of mortality possibly due to religious beliefs (i.e. it is forbidden to kill an animal without cause under Islamic and Hindu law).

4.5.3. Conclusions

There is some evidence to suggest that interviews may prove a useful tool for detecting qualitative changes in abundance; however, a range of cognitive processes, and uncertainty in the boat-based survey abundance trends impacted the conclusions that could be drawn from the data. Informant knowledge can be obtained through a variety of sources thus impacting perceptions of trends and significant threats. The inherent variability in knowledge highlights the need for caution when interpreting informant data along with careful consideration of appropriate informants. Informant data did provide useful insights into the types of threats in the study area, information that may not have been available without intensive ecological surveys. Informant data also revealed the presence of spatial and temporal movement patterns of dolphins which have important implications for conservation management. While these movement patterns require validation with observer surveys, they highlight the potential utility of interviews for studying species movement in regions where resources for monitoring are limited.

Chapter 5. Fishing for the facts: drivers of Ganges River dolphin bycatch in freshwater artisanal fisheries.

A fisher sat in the dense early morning fog of the Lower Karnaphuli River, metres away from a busy cargo ship shipping channel

5.1. Abstract

Fisheries bycatch is a primary driver of declines in cetaceans, prompting research on the factors influencing bycatch rates. However, there is limited information on the factors that influence cetacean susceptibility to bycatch in artisanal fisheries, impeding the development of evidence-based conservation strategies. I carried out 663 interviews with fishers from the Karnaphuli-Sangu rivers complex in southern Bangladesh to investigate a range of net and set characteristics that influence seasonal bycatch rates of Ganges River dolphin (*Platanista gangetica gangetica*) , and assess the sustainability of annual mortality levels. Between October 2010 and October 2011, a total of 170 bycatch events were documented, 89% of which occurred in gill nets. Bycatch presence was higher in larger mesh size nets, and for gill nets set in shallow river depths. While the number of bycatch incidents was higher in gill

nets, the risk of mortality was higher in set bag nets. Based on the Potential Biological Removal equation, and the minimum annual count of fisheries-related mortalities, the current level of annual mortality greatly exceeds the potential annual threshold level of sustainable anthropogenic mortality. While the data highlight potential opportunities for targeted bycatch mitigation, these are unlikely to be successful in the absence of efforts to address low levels of knowledge and compliance with existing fishery laws.

5.2. Introduction

Incidental capture of non-target species, or bycatch, in fisheries is a primary driver of declines in cetaceans, seabirds and sea turtles (Hall, Alverson and Metuzals, 2000; Lewison *et al*., 2004; Wallace *et al*., 2010). It is estimated that the majority of global bycatch occurs in gill nets (Read, Drinker and Northridge, 2006). Bycatch-related mortality is thought to be the principal cause of the decline in the vaquita *Phocoena sinus*, the world's most threatened cetacean species, and the extinction of the Yangtze River dolphin *Lipotes vexillifer* (D'Agrosa, Lennert-Cody and Vidal, 2000; Turvey *et al*., 2007).

Demonstrated declines in the populations of marine wildlife attributable to bycatch have prompted considerable research effort in identifying the factors that affect bycatch rates. Studies have identified a range of factors that can be divided into three categories: fishing gear characteristics (e.g. mesh size, hook type; Kraus *et al*., 1997; Forney *et al*., 2011), set characteristics (e.g. soak time, location, season; Vinther, 1999; Yeh *et al*., 2013), and ecological characteristics (e.g. species, body size; Wallace *et al*., 2008; Yeh *et al*., 2013). While the ecological characteristics influencing bycatch rates are less well understood, improved understanding on the fishing gear and set characteristics have aided the development of a range of bycatch mitigation measures, including: modifications to fishing gear characteristics (e.g. deterrents such as pingers and bird-scaring streamers; (Løkkeborg and Robertson, 2002; Barlow and Cameron, 2003; Palka *et al*., 2008; Dawson *et al*., 2013) and changes in set characteristics (e.g. time-area closures, reduction in effort; Werner *et al*., 2006; Bull, 2007). The addition of acoustic pingers to real-world fisheries (as opposed to controlled trials) can reduce cetacean bycatch by between 50 – 60% (Dawson *et al*., 2013).

While there is a considerable understanding of the factors influencing bycatch rates in commercial fisheries, there is a significant gap in our knowledge on bycatch rates and the sustainability of bycatch in artisanal fisheries (i.e. small, non-industrialised fisheries; Reeves, McClellan and Werner, 2013). Data on bycatch incidents and fishing effort are typically obtained from independent observer programmes, a process that is logistically unfeasible to implement in many artisanal fisheries given their scale. Evidence suggests that artisanal fisheries are capable of driving significant population declines (e.g. Yangtze River dolphin *Lipotes vexillifer*, Turvey *et al*., 2007; North Pacific Loggerhead turtles *Caretta caretta,* Peckham *et al*., 2007), highlighting an urgent need to develop low-cost, rapid and effective methods for assessing bycatch, and improve understanding of the factors influencing bycatch in these fisheries.

Interviews with local informants are increasingly used for obtaining data rapidly, at low cost, and over wide geographical areas, and can provide a long historical perspective on species status where these data would otherwise be absent (Turvey *et al*., 2013). Interviews with local informants have been used to study harvesting practices (Jones *et al*., 2008), population trends (Lozano-Montes, Pitcher and Haggan, 2008), and the nature of bycatch events (López *et al*., 2003; Poonian *et al*., 2008; Álvarez de Quevedo *et al*., 2009; Moore *et al*., 2010; Carruthers and Neis, 2011; Dmitrieva *et al*., 2013; Turvey *et al*., 2013).

Most of the world's freshwater cetaceans are found in developing countries where they frequently interact with artisanal freshwater fisheries. Minimum estimates of bycatch from various locations indicate that entanglement in fishing gear represents a significant source of mortality to freshwater cetaceans. An estimated 87% of Irrawaddy dolphin *Orcaella brevirostris* mortalities in the Mekong River are attributable to entanglement in gill nets, making it one of the most critical threats to this species (Beasley *et al*., 2007). However, there are significant gaps in our knowledge on the nature of these interactions, limiting our ability to develop targeted conservation actions (Reeves, McClellan and Werner, 2013).

In this study interviews were carried out with freshwater fishers in southern Bangladesh to characterise the factors that affect bycatch rates of Ganges River dolphin bycatch in gill nets, and to understand the levels of compliance with existing fishery laws. The sustainability of annual fisheries-related mortality was assessed using the Potential Biological Removal equation according the method of Wade (1998). These data are then used to make recommendations for the conservation of this subpopulation.

5.3. Methods

5.3.1. Study site

Interviews were carried out in fishing settlements across the Karnaphuli-Sangu rivers complex of southern Bangladesh (Figure 5.1). The river complex comprises four interconnected, tidally-influenced waterways: the Karnaphuli River (hereafter divided into the Upper and Lower Karnaphuli at Kalurghat Bridge, based on differences in river morphology and land use), the Sangu River (hereafter divided into the Upper and Lower Sangu at

Dohazari Bridge, based on differences in river morphology), the Halda River, and the Shikalbaha-Chandkhali Canal. There are an estimated 197 (95% CI: 187 - 209) Ganges River dolphins occupying the Karnaphuli-Sangu rivers complex that are potentially isolated from the rest of the global population by a 75 km stretch of the Bay of Bengal (see chapter three).

5.3.2. Data collection

5.3.2.1. Pilot study

In October 2011, a pilot study was carried during which 46 interviews were conducted with fishers in 10 settlements distributed across all four waterways (Figure 5.1). A pilot questionnaire was used to develop an understanding of the types of fishing gear used in the study area, when and where fishing occurs, the units of measurement used by informants, and locally appropriate names for species and fishing gear. Knowledge gained from the pilot study was then used to develop a questionnaire for the main study (Appendix A: Table S1&2). During the pilot study, it became evident that informants were most comfortable using place names to delineate fishing ranges and describe the location of bycatch events, and so I created a database containing the name and GPS location of all bridges, mosques, settlements, *ghats* (small ports for boats) and sluice gates encountered along each waterway.

5.3.2.1.1. Fishing gear description

During the pilot phase, fishers were asked a series of questions to characterise all the types of fishing gear they use throughout the year: 1) Give the names of all the different types of fishing gear you use throughout the year; 2) For each individual gear, please describe the following (where applicable) – mesh size, net length, net depth, number of hooks, presence of floats and weights, what months it is used, where it is used, average soak time, what time of day it is used, material, number of people needed to operate it. Informants were also asked to show the interviewer each gear type so the interviewer could determine if there were any additional gear features that needed describing. Thirty-five types of freshwater fishing gear were described during pilot study interviews (Table 5.1 and Figure 5.2). Gear types were aggregated into eight groups based on their mode of operation: drag nets, gill nets, hand nets, long lines, long shore nets, rod and line, seine nets and set bag nets (Figure 5.2).

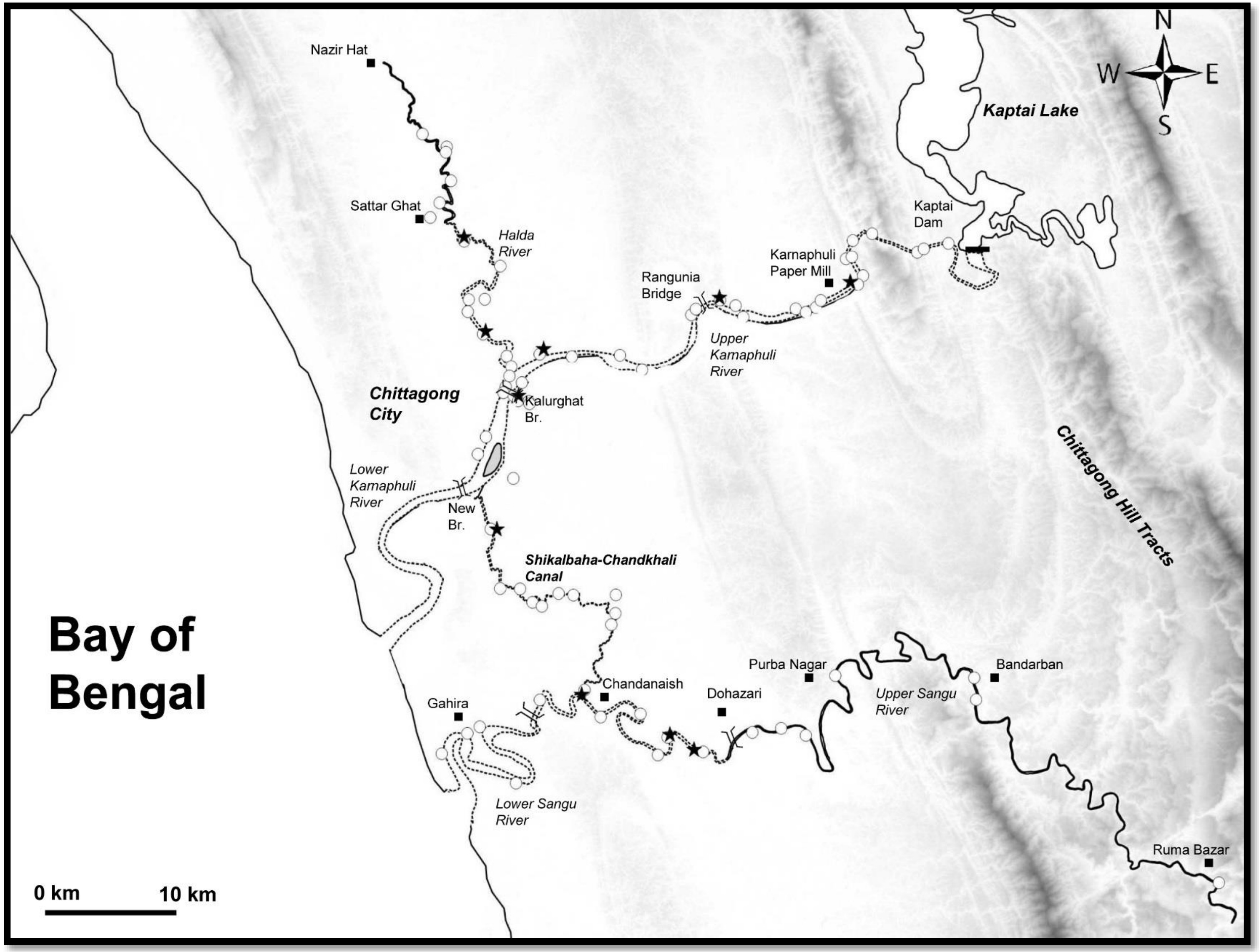

Figure 5.1: Map showing the distribution of pilot study sites (black stars) and interview sites (white circles) across the Karnaphuli-Sangu rivers complex in southern Bangladesh.

Table 5.1: Characteristics of gear types used by fishers within the Karnaphuli-Sangu rivers complex.

Category	Local name(s)	Description	Location(s)	Seasons	Soak time	Time of day	Required manpower	Target species
Drag Net	*Chutki jaal, Dhora jaal, Feling jaal, Moi jaal, Poona jaal, Tango jaal*	A rectangular box net between 2-3 m wide and 1-1.5 m deep. The bottom edge of the net is lined with weights to keep the mouth of the net open when dragged behind a boat. Mesh size ranges from 2-3 cm.	Mainly Lower and Upper Karnaphuli, Halda rivers and Canal with a few people in the Lower Sangu River	All	Up to 60 minutes.	Day	1-2	Penaeid shrimp (*Penaeus indicus*)
Gill net	*Basha jaal*	A monofilament drifting gill net made of nylon. Length varies from 30 to 200 m; depth varies from 1 to 3 m, and mesh size varies from 4 to 8 cm. Floats are evenly distributed along the head line, and earthen weights are fixed along the ground line.	Lower and Upper Karnaphuli, Lower and Upper Sangu and Halda rivers	All, but increased use in the Monsoon to Late Autumn	1-3 hours	Day and night	1-2	Mainly larger species such as Basha (*Eutropiichthys vacha*), Gharua (*Clupisoma garua*)
Gill net	*Current jaal*	A monofilament fixed gill net made of plastic or nylon. Net length varies from 10 to 25 m; depth is one metre; and mesh size varies from 1 to 3 cm. This net is illegal throughout Bangladesh. While these are fixed nets, they are usually supervised by the fisher as they are often actively targeted and destroyed by other fishers as they are seen as one of the most damaging gill nets to fish stocks.	Lower and Upper Karnaphuli and Lower and Upper Sangu rivers	All	Up to 24 hours	Day and night	1	No target species but catches a variety of fish owing to the small mesh size

Gill net	*Fanda jaal*	A fixed monofilament gill net made of nylon. Net length varies from 50 to 200 m; depth varies from 3 to 6 m; and mesh size from 8 to 15 cm. The net is normally set in the upper reaches of a river around the spawning grounds for large, migratory fish species.	Lower and Upper Karnaphuli and Lower and Upper Sangu rivers	All, but main season during which it is used is the Monsoon to Late Autumn	Up to 24 hours	Day and night	1-5	Lakha (*Eleutheronema tetradactylum), Pabda* (*Ompok* spp.), Tengra (*Mystus* spp.), Shilong (*Silonia silonidia*)
Gill net	*Fash jaal, Phasa jaal*	A fixed multifilament or monofilament gill net. Net length varies from 20 to 200 m; depth varies from 1 to 2 m; and mesh size varies from 2 to 4 cm. The net is fixed with bamboo stakes creating an underwater net wall. Floats are used on the headline, and earthen weights along the ground line.	Lower and Upper Karnaphuli, Lower and Upper Sangu and Halda rivers	All, but main season during which it is used is the Late Autumn to Winter	Up to 24 hours	Day and night	1-2	Phasa (*Setipinna phasa*), Pangus (*Pangasius pangasius*), Poa (*Otolithoides pama*), Hilsa (*Tenualosa ilisha*), Bata (*Labeo bata*), Ayre (*Mystus aor*), Foli (*Notopterus notopterus*)
Gill net	*Ilish jaal or Chandhi jaal*	A drifting, monofilament gillnet made of nylon, and less commonly from cotton twine. Net length varies from 200 to 500 m, but can reach up to 800 m; depth varies from 4 to 12 m depending on where in the river it is being used; and mesh size varies from 4 to 8 cm.	Lower and Upper Karnaphuli, Lower and Upper Sangu and Halda rivers	All, but main season during which it is used is the Monsoon to Late Autumn	2-4 hours	Day	1-4	*Chandhi jaal* – juvenile Hilsa, *Ilish jaal* – adult Hilsa.
Gill net	*Punti jaal*	A fixed multifilament or monofilament gillnet made of nylon, or less commonly from cotton twine. Net length varies from 10 to 40 m; depth varies from 0.5 to 1 m; and mesh size from 2 to 4 cm. The net is set on the river bed and is fixed to two bamboo poles.	Sangu and Karnaphuli estuaries	All	Up to 24 hours	Day and night	1-2	Mainly Puntius spp. but also Bata, Bele (*Glossogobius giuris*), Koi (*Anabas testudineus*), Pangus, Poa, and Tengra (*Mystus* spp.).

Hand net	*Hat jaal, Jhaki jaal, Khepla jaal, Jai jaal*	A circular net approximately 3 to 4 m in diameter with weights around the outer edge and an anchoring line in the centre. Normally operated in shallow water from the river bank. Mesh size ranges from 1-2 cm.	All rivers	All	1-2 minutes.	Day	1	No target species. Catches a variety of small fish.
Hand net	*Hathi jaal, Kankra jaal, Tana jaal, Thela jaal, Thirom jaal*	Triangular shaped net made of bamboo poles. The mesh is made from nylon and ranges in size from mosquito net to 2 cm. It is either dragged or pushed through shallow water and occasionally another person will stand in front flushing the fish towards the net.	All rivers	All	1-5 minutes.	Day	1-2	No target species. Catches a variety of small fish.
Long line	*Bora macher borshi*	Fishing line made from nylon or cotton and varying in length from 30-1,000m with fishing hooks set at approximately 30-50 cm intervals.	All rivers	All	2-3 hours	Day	1-2	Lakha, Catla (*Catla catla*) Ruhi (*Labeo rohita*), Mrigal (*Cirrhinus mrigala*), Kalibaush (*Labeo calbasu*).
Long shore net	*Geera jaal*	A long rectangular net that is set on bamboo poles running adjacent to the river bank. Nets can vary from 10-120m. At low tide the net is lowered allowing fish access to the shoreline. At high tide the net is raised on the bamboo poles creating a net wall that traps fish as the tide begins to fall.	All rivers	All	6 hours	Day and night	1-2	No target species. Catches a variety of small fish.
Rod and line	*Wheel borshi*	Fishing rod with reel and Nylon fishing line. Only a single hook on the end.	All rivers	All	5-60 minutes	Day	1	Catla, Ruhi, Mrigal, Kalibaush

Rod and line	*Chingri borshi, sip borshi,*	Single bamboo rod with nylon fishing line and a single hook.	All rivers	All	5-60 minutes	Day	1	Penaeid shrimp
Seine net	*Ber jaal, Dheka jaal, Chiring Macher jaal, Keski jaal, Pona dhorar jaal, Tengra jaal*	A rectangular net ranging from 20 - 1,000 m in length and 2-3 m deep. Mesh size varies from mosquito mesh to 2 cm. One end is held on shore, while the other end is driven by boat in a large arc across the river and then bought back to shore. Both ends are simultaneously pulled to shore by a group of fishers.	All rivers	All	20-40 minutes	Day	2-8	A variety of species, but in particular: Chiring (*Apocryptes bato, Oxyurichthys microlepis*), Keski (*Corica soborna*).
Set bag net	*Behundi jaal, Patoni Jaal*	The set bag net is a large fixed, funnel-shaped net that resembles a trawl net. The mouth of the net faces into the tidal stream and is held open by attaching the wings of the net to two large bamboo stakes that are sunk into the river bed. The mouth of the net varies in depth from 2 to 20 m; length varies from 5 to 30 m; and mesh size from 3-5 cm at the wing tip, to 1 cm to mosquito mesh at the cod-end.	All rivers	All	6 hours	Day	2-8	No target species. Catches a variety of all sizes of fish.

Figure 5.2: Gear types commonly used in the Karnaphuli-Sangu rivers complex: a) Drag net (*Moi jaal*), b) Gill net (*Phasha jaal*), c) Hand net (*Jhaki jaal*), d) Hand net (*Thela jaal*), e) Long line (*Bora macher borshi*), f) Long-shore net (*Geera jaal*), g) Rod and line (*Wheel borshi*), h) Rod and line (*Sip borshi*), i) Seine net (*Keski jaal*), j) Set bag net (*Behundi jaal*).

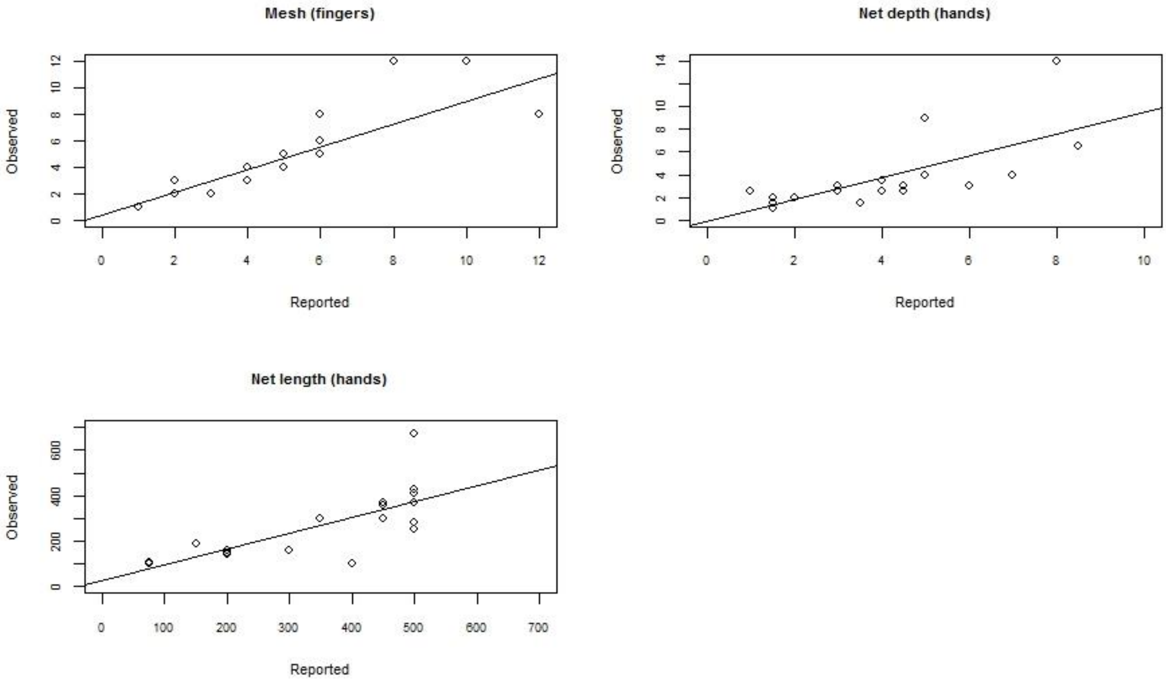

Figure 5.3: Correlation between fisher-reported and observed values for mesh size (fingers), net depth (hands) and net length (hands) from a survey of 28 informants.

5.3.2.1.2. Units of measurement

Fishing gear-related questions revealed that informants commonly use ‘hands’ and ‘fingers’ as units of measurement to describe net length, net depth and mesh size. A ‘hand’ is the distance from the inner elbow to the tip of the longest finger, and ‘finger’ is the width of a finger. Length and depth of nets was simply the number of hands that fit along the edge of the net, and mesh size is the number of fingers that fit into a stretched mesh.

To validate informant measurements we asked a sub-set of informants (n = 28) if they were happy for me to measure their gear, hands and fingers. Informants were asked to describe the mesh size, net length and net depth of a gill net they owned (measurements were provided in hands and fingers). I asked them to indicate the length of a ‘hand’ and ‘finger’ to measure (mean length of one hand and one finger was 35 cm (SD = 2.6) and 1.55 cm (SD = 0.21), respectively). I then measured the gear directly in centimetres and compared the results with those estimated using hands and fingers converted into centimetres. There was a significant relationship between the reported and observed measurements for mesh size (adjusted $R^2 = 0.68$, $p < 0.001$), net depth (adjusted $R^2 = 0.47$, $p < 0.001$) and net length (adjusted $R^2 = 0.56$, $p < 0.001$), although there was considerably more variability for longer length nets (Figure 5.3).

5.3.2.2. *Sampling design and protocol*

See chapter four for details.

5.3.2.3. *Interview survey*

Interviews were carried out with informants between October 2011 and February 2012, usually in the privacy of the informant's home, but sometimes in public or on-board their fishing boat. All interviews were conducted in Bangla (Appendix A, Table S2 for the Bangla version of the interview). Consent was obtained from each informant prior to interview, and all informants were briefed on the objectives of the research and how the data would be recorded, stored and analysed. Each informant was assured that any data they provided were confidential, and that they could withdraw from the interview at any time. Informants were asked a series of questions about the types of gear they use throughout the year, the characteristics of individual gear, level of fishing effort for each gear (i.e. days per week, which months; Appendix A, Table S1, Question 11), the area in which they use each gear type (delineated using settlements or landmarks, Appendix A, Table S1, Question 11), whether there were gears they had stopped using and why (Appendix A, Table S1, Question 12 and 13) and whether they knew of a fishing ban in their area, and when it occurs (Appendix A, Table S1, Question 16 and 17). In order to quantify the number of bycatch events per year, informants were asked to recall all bycatch events between October 2010 and October 2011. They were asked to describe the nature of any known dolphin bycatch events (Appendix A, Table S1, Question 32 and 33), the location of bycatch events to ensure the minimum count of annual bycatch was restricted to the study area (Appendix A, Table S1, Question 32 and 33), and knowledge of any laws protecting the Ganges River dolphin (Appendix A, Table S1, Question 51). If the last recalled bycatch event was more than a year ago, then they were asked to describe this event only. Informants were also asked to confirm whether they had always lived in the study area (Appendix A, Table S1, Question 3). A subset of informants (n = 114) were asked additional questions at the end of the main interview regarding compliance with existing fishery laws and compensation schemes (Appendix A, Table S1, Question A1 – A7).

Fishing gears were assigned to one of six locations (i.e. Halda River, Shikalbaha-Chandkhali Canal, Lower Sangu River, Upper Sangu River, Lower Karnaphuli River, and Upper Karnaphuli River) based on the description provided by the informant of where each gear was used. Gill nets were assigned to one of two net types: drifting or fixed. These assignments were based on the local name provided by the informant during the interview: drifting nets were referred to as *Ilish* and *Basha*; and fixed gill nets were referred to as

Current, *Fash*, *Fanda* and *Punti* (Table 5.1). When reporting net measurements (i.e. net length, mesh size, net depth) informants often provided a measurement range, in which case the midpoint value was used. All measurements were converted to metres and centimetres by multiplying hand and finger measurements by 0.35 m and 1.55 cm respectively.

Informant ability to identify Ganges River dolphins (locally known as *Uchu mach*) was checked at the start of each interview. Informants were asked to identify three species (Ganges River dolphin, and two locally abundant fish species - Phasa, *Setipinna phasa*, and Hilsa, *Tenualosa ilisha*), and describe the habitats in which they occur (i.e. sea, river) from photographs. If the informant struggled to identify the river dolphin clues were given as to the behaviour and size of the animal. Informants were assigned to one of three reliability categories: high (able to correctly identify all species); medium (able to identify river dolphin and one other species); and low (recognised only one species, identified only the fish species, or unable to identify any species).

5.3.2.4. Boat-based surveys

Between December 2011 and February 2012, five boat surveys were carried out across each waterway to quantify the level of fishing effort for each gear type. On each occasion a gear was sighted, GPS location, type of gear (i.e. drag net, gill net, hand net, long line, long shore net, rod and line, seine net, set bag net) and quantity of active gear were recorded. Gear use is dependent on tidal state and time of day with the majority of fishing activity taking place in the early morning or late afternoon. Two surveys were carried out on the incoming tide (one am and one pm), and three surveys on the outgoing tide (two am and one pm).

Depth readings were taken using a hand-held depth sounder (Hondex PS-7), on two of the five surveys, along two transects that ran approximately 50 - 100 m from the river bank on either side of the river. Depth readings and GPS waypoints were taken approximately every 350 m. A depth value was also assigned to each gear type. Using the area over which the informant uses each gear type, geo-referenced depth readings from the two boat surveys were overlaid. The depth profiles of river dolphin habitat can exhibit considerable heterogeneity over relatively small areas with the occasional presence of deep pools and shallow sand bars (e.g. Braulik *et al*., 2012b), and so median river depth was assigned to each gill net to avoid over or under-estimating river depth across the range.

5.3.3. Data analysis

5.3.3.1. Interview sample and representativeness of the overall population

To validate the representativeness of the interview sample I compared the number of gill nets, long shore nets, seine nets and set bag nets used in the winter season (as reported during the interview survey) against the mean number observed during winter boat-based surveys for each location. Comparisons were restricted to the winter season as there were no observer surveys of gear use during other seasons. Comparisons were excluded for long-lines, hand nets, drag nets and rod and lines as their use is very variable/ non-existent during the winter season. The comparison assumes that all available gill nets and set bag nets in the study area were available for detection during the observer boat-based surveys. The pilot surveys revealed that the majority of gill net use occurs during the day (i.e. 96%, n = 46/48) and for six to seven days a week (86%, n = 41/48).

5.3.3.2. Characteristics of fishing gear and effort

To investigate seasonality in gear use, I calculated the number of gears used in each of the six seasons (i.e. winter, spring, summer, monsoon, autumn, late autumn) for the most common gear types using the informant data. In an attempt to validate the distribution of gill net use across the study area I compared the number of gill nets used at each location during the winter season as reported during interviews, against the number of all gill nets observed during the winter season boat-based surveys. Comparisons were not carried out for other seasons as observer surveys of gear types were only available for the winter season.

5.3.3.3. Factors affecting presence of dolphin bycatch in gill nets

The analysis of factors affecting the presence of dolphin bycatch was restricted to gill nets, as there were too few bycatch events in other gear types. I used a logistic generalised linear model (glm) with binomial error structure to explore the effect of net and set characteristics (see Table 5.2) on the presence of river dolphin bycatch in an individual gill net (dolphin bycatch present [1]; dolphin bycatch not present [0]) per season. The analysis was restricted to bycatch events between October 2010 and October 2011 as informants were only asked to recall all annual bycatch events from this period. The response was modelled over a season as fishers described gill net use by season due to the availability of particular fish species, and bycatch events were reported by season. Furthermore, the response was modelled as binary rather than a count (i.e. bycatch rate or number of bycaught individuals) as there was little variability in the number of bycaught dolphins per season (i.e. gill nets with only one bycaught dolphin = 98% cases) and number of days fished per season (i.e. mean number of days fished = 52; SD = 4.8).

Table 5.2: Net and set variables considered for use in the models investigating the factors influencing the probability of Ganges River dolphin bycatch.

Variable	Definition	Unit
Net characteristics		
Mesh size (continuous)	Inside stretched distance between two knots on opposite sides of the same mesh	Centimetres
Net length (continuous)	Length along the longest edge of the net	Metres
Net depth (continuous)	Length along the shortest edge of the net	Metres
Net type (categorical)		Drifting Fixed
Percentage water column depth covered by net	Net depth/ median water depth	Percentage
Set characteristics		
Location (categorical)		Upper Karnaphuli River Lower Karnaphuli River Halda River Lower Sangu River Shikalbaha-Chandkhali Canal
Season (categorical)		Monsoon (mid-Jun to mid-Oct) Non-Monsoon (mid-Oct to mid-Jun)
Median river depth (continuous)		Metres

Predictor variables included net characteristics (mesh size, net length, net depth, net type, and percentage of water column covered by the net [i.e. net depth/ median river depth]) and set characteristics (median river depth, season and location; Table 5.2). The relationship between the response and continuous predictor variables was inspected for non-linearity using generalised additive model (GAM) plots fitted with cubic smoothing splines using the 'mgcv' package in R version 3.0.1 (R Core Team, 2013). Continuous variables were plotted in their linear, log and quadratic forms. An offset term using a measure of fishing effort was not included due to the lack of variability in days fished per season.

Variables from fisheries data can exhibit considerable multi-collinearity (e.g. the use of larger mesh size nets in particular seasons). Variance inflation factors (VIF) were used prior to model building to identify collinear variables using the 'corvif' function in the package AED in R. VIF scores exceeding 3 were considered as evidence of collinearity (Zuur *et al*. 2009).

Where collinear variables were identified the variable that explained a greater proportion of model variance was retained.

The following data were excluded from the analysis: data from the Halda River and Shikalbaha-Chandkhali Canal where there was no gill net fishing effort; gill nets used north of Purba Nagar on the Upper Sangu River as there are no visual sightings of dolphins in this area; retired fishers; nets used in multiple locations as it was not possible to assign them to a single location; and informants with a ‘low’ reliability score during the species identification exercise. The final data set contained 511 observations from 446 informants.

A global model was developed containing all possible combinations of the predictor variables and interactions, and was fitted in R version 3.0.1 (R Core Team, 2013). Backward stepwise selection was used for identifying the best model according to Akaike’s information criterion (AIC). Model selection was based on ΔAIC (the difference in AIC between each model and the ‘best’ model or the model with the lowest AIC) in which the top models had a Δ AIC less than 2 (Burnham and Anderson, 2002). Model fit was assessed using the Hosmer-Lemeshow test from the ‘binomTools’ package in R. Coefficient estimates from the best model were then used to predict bycatch probability per individual gill net per season at varying mesh sizes (i.e. 1 cm to 11 cm) and river depths (i.e. 1 m to 12 m) at the three locations (i.e. Lower Karnaphuli, Lower Sangu and Upper Karnaphuli).

5.3.3.4. Annual mortality and factors affecting the outcome of bycatch

A count of minimum annual fisheries-related mortality was calculated by summing the number of bycaught animals that were killed, found alive but then died, and found dead, in all net types for the period October 2010 to October 2011. All reported bycatch events were confirmed as having occurred within the study area. As the sample of bycatch events was obtained non-randomly, the mortality count was not extrapolated to the entire population of informants and therefore represents a minimum count only.

Chi-squared tests were used to test for significant differences in the frequency of mortalities in gill nets and set bag nets. Bycatch events were assigned to one of two outcomes: alive or dead. Bycaught dolphins discovered alive in nets but subsequently killed, or discovered alive but died during release, or found dead were assigned to the ‘dead’ outcome. To maximise sample size, data were used from recorded bycatch events across all time periods (i.e. October 2010 to 1986) but were restricted to gill net and set bag nets only as there were too few events in other net types.

5.3.3.5. Validating mortality levels using a mortality monitoring network

In an attempt to validate numbers of annual mortalities from local informant data, a mortality monitoring network was established. Following each interview, informants were issued with a phone number to call if they experienced/ heard of a dead dolphin, or experienced/ heard of an entanglement incident. Informants were told that they would not receive any rewards for reporting mortalities or net entanglements so as not to encourage intentional capture or killing of dolphins.

5.3.3.6. Potential annual threshold levels of sustainable anthropogenic mortality

The Potential Biological Removal (PBR) equation (Wade, 1998) was developed specifically for marine mammals under the US Marine Mammal Act and has been widely used to define potential annual threshold levels of sustainable anthropogenic mortality for species such as killer whales (*Orcinus orca*; Williams, Lusseau, & Hammond, 2009), dugongs (*Dugong dugon*; Marsh *et al*., 2004), Harbour porpoises (Berggren *et al*., 2002), Harbour seals (*Phoca vitulina*; Thompson *et al*., 2007), Harbour and Dall's porpoises (*Phocoenoides dalli*), and Pacific White-sided dolphins (*Lagenorhynchus obliquidens*) (Williams, Hall and Winship, 2008). The equation has also been modified for use on other species, including albatrosses and petrels (Dillingham and Fletcher, 2011), and turtles (Finkbeiner *et al*., 2011).

Using the mean winter 2012 population estimate (n = 197, 95% CI: 187-209, CV = 3%; see chapter three), potential annual threshold levels of sustainable anthropogenic mortality were estimated using the PBR equation:

$$PBR = N_{MIN} \frac{1}{2} R_{MAX} F_R \qquad [5.1]$$

where N_{min} is the 20th percentile of a log-normal distribution of the mean abundance estimate ($\hat{N}$) and is estimated as follows:

$$N_{\min} = \hat{N} / \exp(0.842 \cdot (\ln(1 + \mathrm{CV}(\hat{N})^2))^{1/2}) \qquad [5.2]$$

And R_{MAX} is maximum population growth rate, CV is the coefficient of variation of the mean abundance in winter 2012 and F_R is the recovery factor. An R_{MAX} value is rarely available for cetaceans and so a default value of 4% is recommended by Wade (1998). Default values for the recovery factor are 0.1-0.3 for endangered/ declining populations, 0.4-0.5 for depleted/

threatened stocks and stocks of unknown status, and up to 1.0 for stocks known to be at optimum levels, or of unknown status but known to be increasing (Barlow *et al*., 1995).

Potential annual threshold levels of sustainable anthropogenic mortality were estimated using a range of values for abundance, the recovery factor and R_{MAX} to account for the uncertainty in these parameters. For abundance, I used the mean estimate from the winter 2012 surveys (i.e. 197 individuals) and the lower and upper abundance estimates based on the sensitivity analysis (i.e. 185 [95% CI: 177-198] and 211 [95% CI: 198-227]) individuals; see chapter three). I used two values for R_{MAX}: the default value of 0.04 which is a conservative estimate for the rate of population growth; and 0.07 which represents a high estimate of net productivity from a healthy Dusky dolphin population (Dans *et al*., 2003). I used all 10 values between 0.1 and 1.0. This analysis assumes that the Karnaphuli-Sangu rivers complex is a closed population which will be discussed.

5.3.3.7. Knowledge of local fishery laws and levels of compliance

I estimated the proportion of informants who knew of local laws (fishing bans, gear restrictions) within the area they go fishing, what these laws are, when these laws occur, whether they comply with these laws and whether there are any compensation schemes in place during fishing bans. I also calculated the proportion of informants who knew of any law protecting the Ganges River dolphin. Data from informants who fish in multiple locations, retired, or received a 'low' reliability score during the species identification exercise were discarded resulting in a final data set of 580 informants.

5.4. Results

5.4.1. Interview sample and representativeness of the overall population

A total of 663 interviews were carried out in 74 settlements across the study area (i.e. the one km buffer strip surrounding each waterway); however, only two lines of evidence suggest that interview teams sampled a major proportion of the fisher population within the one km buffer strip (note that I refer to the riverine fisher population and do not include marine or freshwater inland pond fishers): 1) interview teams visited every settlement they could find within the study area (other than the tribal settlements north of Bandarban, and the settlements north of Kaptai Lake) and failed to find any other fisher settlements; 2) the comparison of numbers of each gear type reported during interviews and observed during boat-based surveys were similar (Figure 5.4). The comparison of numbers of each net type from the two data sources suggests that interview data overestimated the number of gill nets, long shore nets, and seine nets in use in the winter season with respect to the boat-based observer surveys (Figure 5.4). However, these discrepancies were small and more likely to be indicate the fact that while informants reported fishing most days of the week, they do not necessarily fish every day or during the times the observer surveys were conducted.

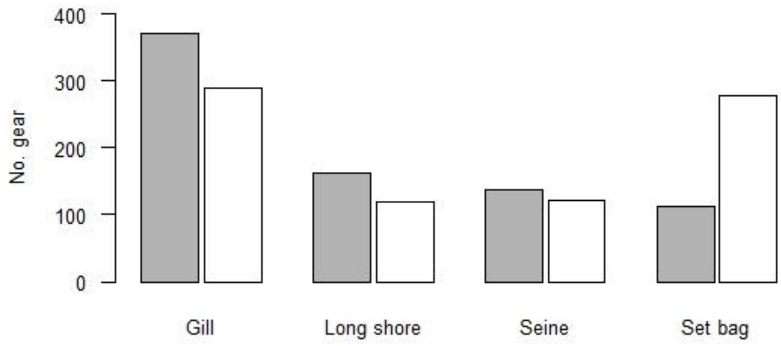

Figure 5.4: A comparison of informant-reported numbers of each gear type used during the winter season (grey bars) and numbers observed during boat-based surveys during the winter season (white bars).

Furthermore, some gear types were difficult to detect; for example *punti jaal* (i.e. bottom-set gill nets) are set on the river bed and have no floats on the surface. However, *punti jaal* constitute only 5% of all described gill nets and so are unlikely to significantly bias the observed estimates of numbers of gill nets. The comparison of the two data sources suggests that set bag net fishers were under-represented in the interview sample, or that numbers may have been under-reported during interviews. The disparity between data sources may reflect an incomplete interview survey of fishers using these gear types, or it may reflect a tendency for fishers to have under-reported these gear types during interviews. While acknowledging there are sampling biases associated with each method, this comparison illustrates that the interview sample covered a major proportion of the fisher population in the study area.

5.4.2. Characteristics of gear and fishing effort

Based on the interview data, a total of 78 drag nets, 1,027 gill nets, 326 hand nets, 59 long lines, 64 long-shore nets, 44 rod and lines, 137 seine nets and 196 set-bag nets were documented within the study area (Figure 5.5a). While gill nets were the most dominant gear type, they exhibit considerable seasonality in their use with a peak in the monsoon (i.e. mid-June to mid-August) when the number of active nets almost doubles relative to the spring (Figure 5.5b). Informants attribute this peak to the migration of large, economically important species into the study area, namely Hilsa (*Tenualosa ilisha*), Catla (*Catla catla*) Ruhi (*Labeo rohita*), Mrigal (*Cirrhinus mrigala*) and Kalibaush (*L. calbasu*).

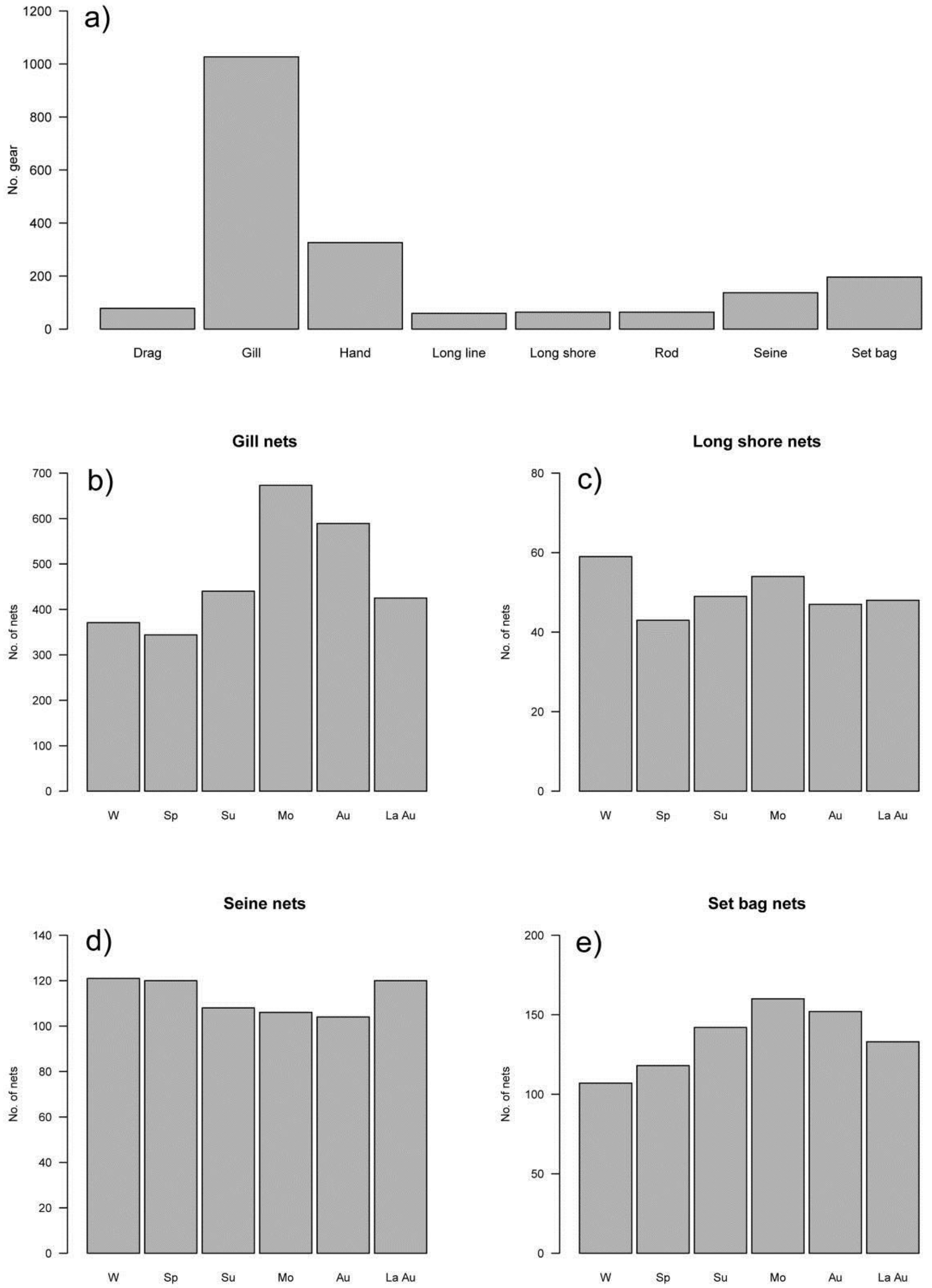

Figure 5.5: Numbers of the each gear type (based on interview data) used throughout the year (a), and numbers of gill nets (b), long-shore nets (c), seine nets (d) and set bag nets (e) used in each of the six fishing seasons (w = winter, Sp = spring, Su = summer, Mo = monsoon, Au = autumn, La Au = late autumn).

Long-shore nets, seine nets and set bag nets exhibit less seasonality in their use relative to gill nets (Figure 5.5c, d, e) because they a) are non-selective gear so can be used to catch species in all seasons, and b) are expensive to purchase and so fishing is carried out all year round to maximise the financial return. Hand nets, rod and line and long lines are considered 'casual use' gear that are used throughout the year and typically in the time-gap between deploying and checking gill nets and set bag nets. There is an uneven distribution of gill net use between each location, though there is a disparity between informant data and observed data in terms of the actual numbers of gill nets used at each location (note the comparison of interview and observed data refers to the winter season only as there was no observational data available for other seasons). Informant data and observational data of active gill nets in the winter season show similar patterns in the distribution of effort, with high numbers of nets in the Upper Karnaphuli (interviews=65; mean of observer surveys = 47 [SD=6]) and Lower Karnaphuli (interviews=49; mean of observer surveys = 57 [SD=7]), and lower numbers in the Sangu (interviews=23; mean of observer surveys = 16 [SD=4]) and Halda (interviews=12; mean of observer surveys = 6 [SD=4]) rivers.

5.4.3. Bycatch incidents between October 2010 and October 2011

Informants recalled a total of 304 unique bycatch incidents dating back to 1986 (Table 5.3), of which 248 had sufficient detail on associated net characteristics. Of the 170 bycatch incidents recorded between October 2010 and October 2011 (Table 5.3), the majority occurred in gill nets (89%), followed by set bag nets (10%).

Table 5.3: Total number of bycatch events (Total [released alive, killed, alive but died during release, released dead]) between October 2010 and October 2011, and between October 2010 to 1986.

Gear type	No. bycatch events between Oct 2010 – Oct 2011 (**Total** [alive, killed, alive but died, dead])	No. bycatch events between 1986 - Oct 2010 (**Total** [alive, killed, alive but died, dead])*
Drag nets	**0** [0, 0, 0, 0]	**0** [0, 0, 0, 0]
Gill nets	**151** [143, 2, 1, 5]	**62** [46, 2, 3, 11]
Hand nets	**0** [0, 0, 0, 0]	**2** [1, 0, 0, 1]
Long line	**2** [1, 0, 0, 1]	**8** [5, 0, 0, 3]
Long shore	**0** [0, 0, 0, 0]	**0** [0, 0, 0, 0]
Rod and line	**0** [0, 0, 0, 0]	**0** [0, 0, 0, 0]
Seine net	**0** [0, 0, 0, 0]	**8** [4, 3, 0, 1]
Set bag nets	**17** [12, 0, 0, 5]	**54** [30, 2, 1, 21]
Total	**170** [156, 2, 1, 11]	**134** [86, 7, 4, 51]

* Note that for bycatch events further back than October 2010 informants were not asked to recall every bycatch event each year, simply the last one they could remember.

Of the 170 bycatch events that occurred between October 2010 and October 2011, 51 were reported in the Lower Sangu, 40 in the Upper Karnaphuli, 27 in the Lower Karnaphuli, 19 in the Halda and 33 in the Shikalbaha-Chandkhali Canal. No bycatch incidents were recorded in drag nets, long shore nets or using rod and line. Four bycatch events were recorded in seine nets; however, further questioning of informants revealed that nets were intentionally encircled around the dolphins so they could be killed, indicating that these events did not represent accidental "bycatch" but instead targeted catch. Informants who use only larger-mesh nets (>5cm) reported depredation of species (n = 110; in particular Hilsa and catfish species), relative to informants who use only small-mesh nets (<5cm, n = 47).

5.4.4. Factors affecting bycatch of river dolphins in gill nets

5.4.4.1. Logistic generalised linear model

Net depth, percentage of the water column covered in net were excluded from the analysis based on VIF scores due to collinearity with mesh size and median river depth. Furthermore, net depth, percentage of the water column covered in net resulted in higher AIC values relative to mesh size and median river depth. The six Bangladeshi seasons were grouped into two distinct seasons (monsoon, mid-June to mid-October, and non-monsoon, mid-October to mid-June) based on it generating a lower AIC score. GAM plots revealed non-linear relationships between the response variable (i.e. presence of bycatch) and mesh size and median river depth, but both were linearised with log transformations.

Model selection favoured a single model (i.e. Δ AIC<2) retaining mesh size, location, season and median river depth. The probability of bycatch at varying depths and mesh sizes showed similar patterns across each of the locations (i.e. declines with decreasing mesh and increasing median river depth), although the actual bycatch probability differed (Figure 5.6, Figure 5.7 and Figure 5.8). Overall, there was a higher probability of bycatch occurring in the Lower Sangu River relative to the Lower and Upper Karnaphuli for all depths and mesh sizes, and a higher probability of bycatch in monsoon months relative to non-monsoon months (Figure 5.6, Figure 5.7 and Figure 5.8). For a gill net with a mesh size of 4 cm (mean mesh size for a gill net in the study area) operated at a median river depth of 1 m, there was atleast a 70% probability of bycatch occurring in non-monsoon months and 90% in monsoon months. For any mesh size net there was at least a 10% probability of bycatch occurring for nets used at a median depth of 1 m.

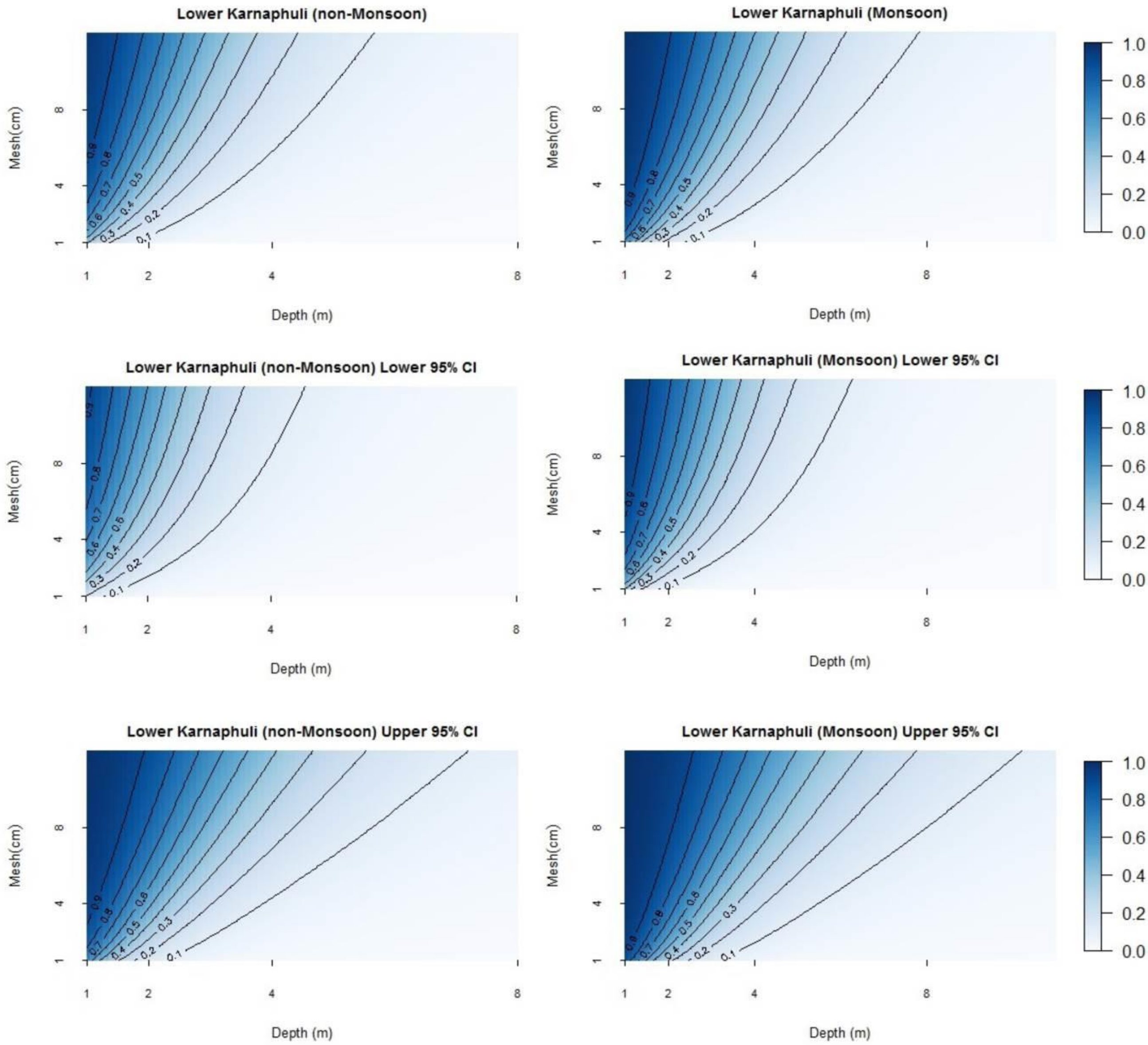

Figure 5.6: Probability of bycatch presence in gill nets during non-monsoon and monsoon seasons in the Lower Karnaphuli River with lower and upper 95% confidence limits. The four lower plots represent the upper and lower confidence limits. Contour lines and shading indicate the probability of bycatch.

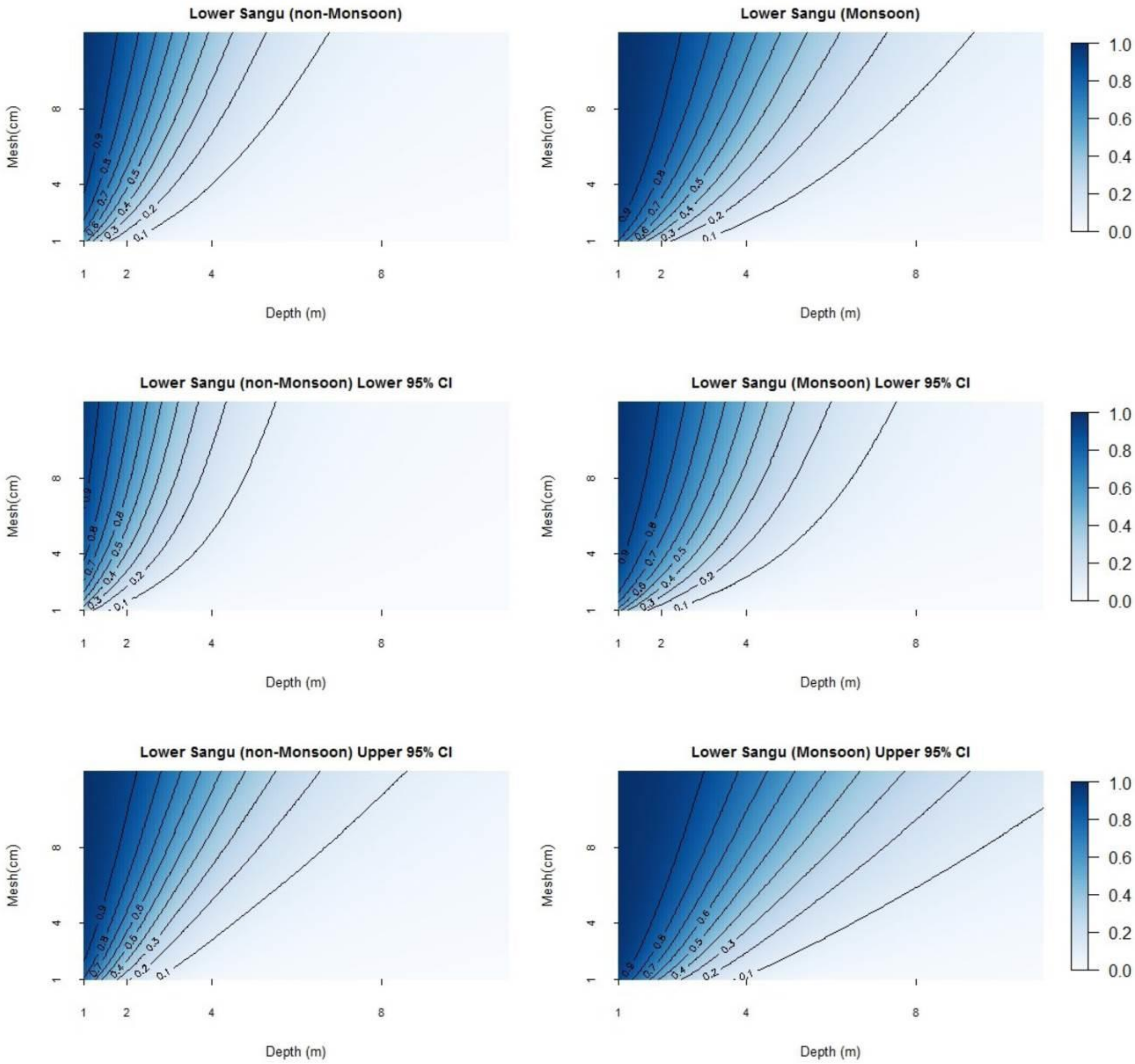

Figure 5.7: Probability of bycatch presence in gill nets during non-monsoon and monsoon seasons in the Lower Sangu River with lower and upper 95% confidence limits. The four lower plots represent the upper and lower confidence limits. Contour lines and shading indicate the probability of bycatch.

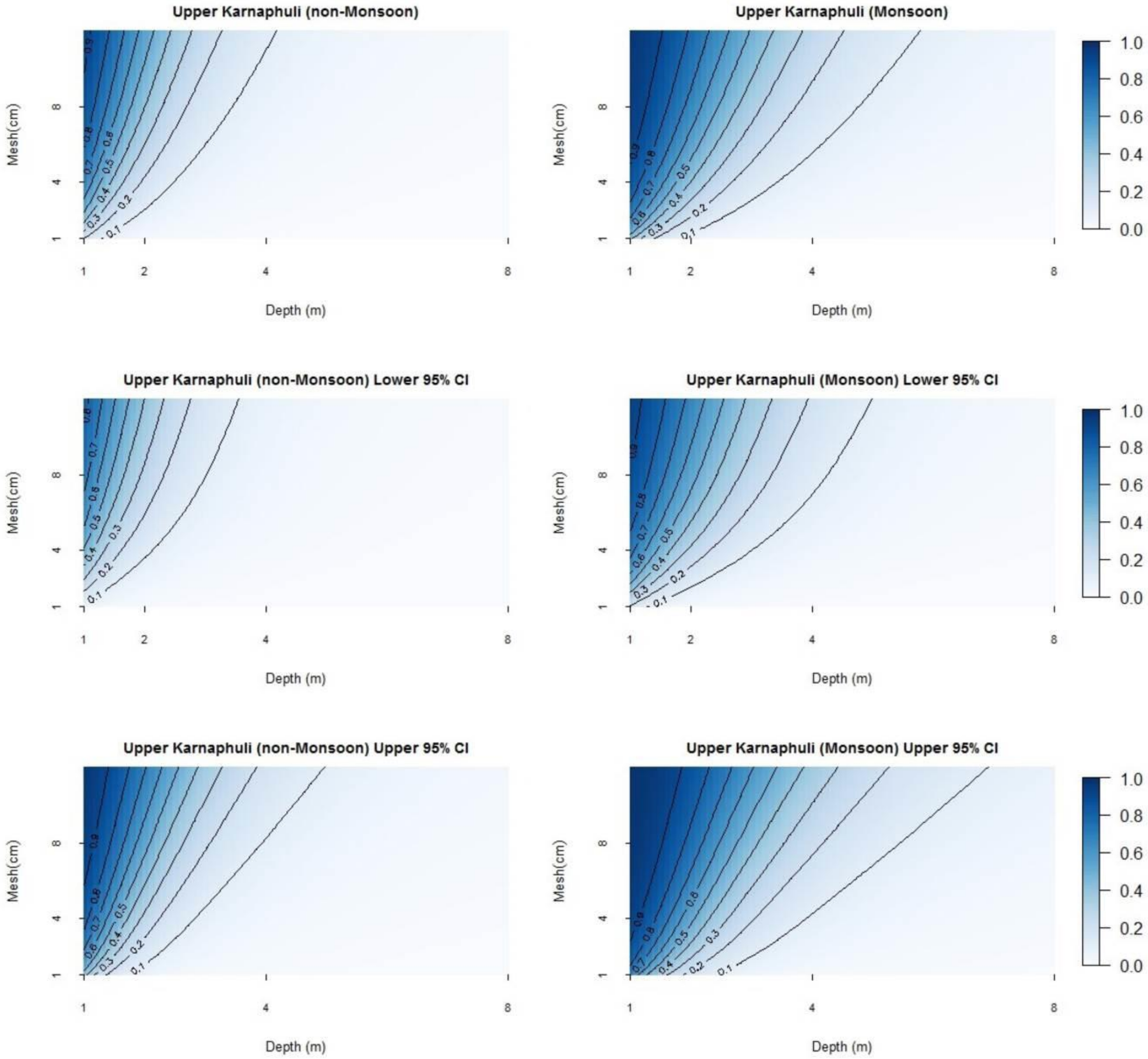

Figure 5.8: Probability of bycatch presence in gill nets during non-monsoon and monsoon seasons in the Upper Karnaphuli River with lower and upper 95% confidence limits. The four lower plots represent the upper and lower confidence limits. Contour lines and shading indicate the probability of bycatch.

5.4.5. Annual mortality and the outcome of bycatch events

Of the 170 bycatch events reported during interviews between October 2010 and October 2011, 14 were reported dead (i.e. sum of killed, alive but died, dead); eight in gill nets, five in set bag nets, and one in a long line (Table 5.3). Of the 14 mortalities, three were alive at the point they were discovered in nets, one of which was killed for its oil and one which was killed as punishment for tearing the fisher's net. The mortality count represents a minimum count only, as the comparison of nets reported and observed in the winter season indicates that set bag nets were under-represented in the interview sample (Figure 5.4). Furthermore, three fishers from the Upper Sangu River (i.e. Bandarban and Ruma Bazar) reported that 'tribal people' of the Chittagong Hill Tracts, shoot and spear dolphins during the monsoon, however, due to visa restrictions I was unable to interview tribal communities and validate these reports.

Based on the mortality events reported between October 2011 and 1986, a significant difference was detected in the outcome (dead/alive) of dolphins caught in gill nets and set bag nets (χ^2 = 261.7, d.f. = 2, $p < 0.0001$) with 68% of all set bag net bycatch events resulting in mortality relative to only 13% of gill net bycatch events. The majority of all set bag net bycatch events occurred in the Shikalbaha-Chandkhali Canal (n=15/17), representing 36% of the annual mortality in this one location (i.e. n=5/14).

5.4.6. Validation of annual mortality levels

Between November 2010 and February 2011 the mortality monitoring network confirmed two dolphin mortalities and received reports of a further two. The two confirmed mortalities occurred on the 13th of November 2011 in the Halda River and the 14th of December at the confluence of the Shikalbaha-Chandkhali Canal and Lower Karnaphuli River. One of the unconfirmed mortalities was reported from the Lower Karnaphuli River and the other from the Lower Sangu River. Cause of death could not be established for the Halda River mortality due to the severe state of decomposition (Appendix B, Figure S1). Cause of death for the Shikalbaha-Chandkhali Canal mortality was confirmed as gill net entanglement in an *Ilish jaal* (i.e. Hilsa gill net) based on an examination of the carcass and an interview with the owner of the net (Appendix B, Figure S2).

While I could not validate the existence of two mortalities, multiple reports were received from numerous surrounding settlements of what appeared to be the same mortalities. Data from the mortality monitoring network suggest that mortalities occur at a rate of around one a month, though this rate must be taken in the context of a very limited sample size.

Furthermore, the mortality monitoring network collected data during the dry season months (late autumn [mid-October to mid-December], and winter [mid-December to mid-February]) that, according to informant data, is when the least number of fishing gear-related mortalities are expected to occur, suggesting that a rate of one mortality a month is an underestimate.

5.4.7. Potential annual threshold levels of sustainable anthropogenic mortality

Irrespective of the proposed abundance estimate and the recovery factor, reported levels of annual mortality greatly exceed the maximum threshold level of sustainable anthropogenic mortality (Table 5.4). Under a best-case scenario in which the current subpopulation size is 211 individuals (the upper abundance estimate from the sensitivity analysis in chapter three), abundance is assumed to be increasing (recovery factor = 1.0) and the R_{MAX} is 7%, the subpopulation can sustain a maximum of 7.2 anthropogenic mortalities per year (Table 5.4).

Table 5.4: Potential annual threshold levels of sustainable anthropogenic mortality (i.e. number of individuals that can be lost from the population) based on the Potential Biological Removal equation using the mean 2012 winter abundance estimate (i.e. 197), the upper and lower abundance estimates from the sensitivity analysis in chapter three (i.e. 185 and 211), all possible recovery factors F_R (i.e. 0.1 to 0.5), and 4% and 7% for the recovery factor.

$\hat{N}$	N_{MIN}	R_{MAX}	CV	RECOVERY FACTOR (F_R)									
				0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**
185	168	4%	3%	0.4	0.7	1.1	1.4	1.8	2.2	2.5	2.9	3.2	3.6
185	168	7%	3%	0.6	1.3	1.9	2.5	3.2	3.8	4.4	5.1	5.7	6.3
197	179	4%	3%	0.4	0.8	1.2	1.5	1.9	2.3	2.8	3.1	3.4	3.8
197	179	7%	3%	0.7	1.3	2.0	2.7	3.4	4.0	4.7	5.4	6.1	6.8
211	191	4%	3%	0.4	0.8	1.2	1.6	2.1	2.5	2.9	3.3	3.7	4.1
211	191	7%	3%	0.7	1.4	2.2	2.9	3.6	4.3	5.0	5.8	6.5	7.2

5.4.8. Fishery status, and knowledge and compliance with fishery laws

Ninety seven percent of informants (n = 563/580) reported that fish stocks in the river complex declined significantly between 2001 and 2011. Nineteen percent of informants (n = 110/580) also reported that they have been forced to sell large-mesh size nets as many larger-sized fish are no longer available. Results from the question regarding fishing bans and gear-use restrictions in the study area, along with data collected from the fisheries department, revealed that there are a total of 15 laws in place throughout the year (Table 5.5). Informants demonstrated varying levels of knowledge regarding the timing and presence of fishing bans and gear-restrictions with 60% (n = 348/580) of informants reporting that they had no knowledge of any fishery regulations in their fishing area. Of the

40% (n = 232/580) who knew of a fishing ban, 67% (n = 155/232) couldn’t remember when the ban occurred.

Interviews with a subset of informants (n = 114), revealed that the local government offers a 10 kg sack of rice per fisher household as compensation for the loss of earnings during the ban; however, 65% of informants (n = 74/114) reported they received the rice infrequently and 28% (n = 32/114) reported that they had never received any rice. Fifty two percent (n = 302/580) of the interviewed sample relies solely on fishing as a source of income. Eleven percent (n = 12/114) of informants also mentioned that they were in debt to local ‘rich people’ or ‘loan sharks’ known as *Mohajan*, and that they continue to fish illegally during the ban so they can make loan repayments as they fear being beaten and having all their assets (i.e. nets and canoe) taken away from them.

Seven percent of informants (n = 40/580) admitted to using banned gear types (i.e. *current jaal* or mosquito-sized mesh nets). Three percent (n = 17/580) claimed that they are forced to use small-mesh gill nets as fish stocks have declined and so they need to maximise their fishing yield to feed their families. Furthermore, five informants reported that they had observed fishers on the Sangu and Upper Karnaphuli rivers using poison fishing methods for catching fish. They indicated that poison fishing typically takes place at night to evade detection by the fisheries department and by other fishers, and involves dropping large quantities of dichlorodiphenyltrichloroethane (an insecticide commonly referred to as DDT), into the river to kill everything within the vicinity. Gill nets are then set across the river to harvest the dead fish. Only two (retired) of all the interviewed informants (n = 663) knew of a law protecting the Ganges River dolphin. Both informants were interviewed in settlements bordering the Sangu River, and had been previously interviewed in 2004 by researchers from Chittagong University whom had informed them of the law.

Table 5.5: Details of fishery laws in place in the study area. These data were obtained from local informants and documents from the fisheries department.

Type of law	Law	Timing	Location
Gear ban	Plastic gill nets (*current jaal*)	All year	All
	Ban on the use of fish aggregating devices (i.e. brush shelters, water hyacinth beds)	All year	All
	Ban on the use of explosives and weapons for harvesting fish	All year	All
	Ban on the use of poison for harvesting fish	All year	All
Mesh size restriction	Small mesh gill nets where stretched mesh size <4.5 cm (*current jaal*)	All year	All
	Gill nets with a stretched mesh size <10 cm in Hilsa fishery	All year	All
Species size restriction	Ban on capture fry and brood of Snakehead (*Channa punctata*) unless for culture	All year	All
	Ban on harvesting fry, fingerling, brood stock of carp species (Rui, Catla, Mrigal, Kalibaush, Gonia) unless for culture	November to May	All
	Ban on harvesting young Hilsa < 23 cm	November to May	All
	Ban on harvesting Pangus < 23 cm	November to April	All
	Ban on harvesting Shilong < 30 cm	February to June	All
	Ban on harvesting Shol < 30 cm	February to June	All
	Ban on harvesting Ayre < 30 cm	February to June	All
Seasonal closure	Ban on all fishing activity, except the fishers employed by the government to harvest carp eggs	February to July	Halda
	Ten day ban on all fishing activity every year to protect Hilsa brood stock	10 days in October	Hilsa spawning sites

5.5. Discussion

5.5.1. Drivers of river dolphin bycatch in freshwater fisheries

Gill net fisheries are globally recognised for their significant contribution to overall bycatch levels of marine wildlife (Read, Drinker and Northridge, 2006). Freshwater cetacean bycatch in gill nets is well-documented (e.g. Biswas and Boruah, 2000; Beasley *et al*., 2007; Mansur *et al*., 2008), and bans/ regulation of gill nets have been recommended (e.g. Choudhary *et al*., 2006; Sinha, Behera and Choudhary, 2010; Kreb *et al*., 2010), but there is limited information on the spatial and temporal patterns of bycatch, hindering the development of targeted conservation actions. The data presented here highlight some potential opportunities for targeted actions to mitigate a proportion of the Ganges River dolphin bycatch in the Karnaphuli-Sangu rivers complex.

The results show a higher probability of bycatch occurring in gill nets operated in shallow river sections. At shallow depths bycatch probability is expected to be particularly high as gill nets cover a greater proportion of the water column effectively creating a barrier to dolphin movement. Given the reported decline in river depth over the last ten years in the Sangu and Upper Karnaphuli rivers (chapter three and four) and observed declines in river depth across many other parts of the species' range (e.g. Choudhary *et al*., 2012), bycatch rates may be expected to increase in the absence of efforts to preserve deep river channels that are important for dolphin movement.

The data showed a positive association between the likelihood of bycatch and gill net mesh size, a pattern frequently observed in marine gill net fisheries and attributed to selectivity of particular prey species (Palka *et al*., 2008). While there is little published information on the dietary preferences of Ganges River dolphins, fishers frequently reported depredation of medium and larger sized fish such as Hilsa and catfish, species that are commonly targeted using larger-mesh (> 5 cm) gill nets. The increased probability of bycatch in larger mesh nets may also reflect an association between net depth and bycatch probability. Larger mesh nets are wider (as demonstrated by the correlation between net depth and mesh size) and therefore cover a greater proportion of the water column.

While I could not test for the effect of dolphin density on the probability of bycatch, the data suggest that dolphin abundance hotspots may be a useful criterion for protected area site selection in the study area. Waterways with higher dolphin encounter rates had higher overall probabilities of bycatch occurring in both monsoon and non-monsoon months, though it should be noted that the data on encounter rates are based on observations from the winter season only. Furthermore, this criterion may only apply for reducing gill net bycatch. While there were fewer bycatch events in the Shikalbaha-Chandkhali Canal relative to the Sangu, Lower and Upper Karnaphuli rivers, the greatest proportion of all mortalities occurred in the canal where the dolphin density is relatively low but set bag net use is high.

Unfortunately I was unable to investigate the effect of fishing effort on the probability of bycatch during each season. Studies suggest there is an increase in fishing effort during the monsoon; however, using the informant data I was unable to detect a significant difference in the mean number of days fished between the monsoon and other seasons. Changes in seasonal bycatch probability may indicate a change in fishing behaviour. Data from informal discussions with informants indicated a preference for setting nets in shallow, narrow, river reaches during the monsoon to block the route of migratory fish into the upper reaches of rivers; however, this could not be validated due to the lack of observational surveys in the monsoon.

5.5.2. Sustainability of fisheries-related mortality and potential biases

Fisheries-related mortality is believed to represent one of the most significant threats to Ganges River dolphins (Mohan, 1995; Smith & Reeves, 2000; Smith *et al*., 2004; Choudhary *et al*., 2006) but the sustainability of mortality levels has never been quantified. The results of this study provide evidence that the current level of fisheries-related mortality in Ganges River dolphins is likely to be unsustainable and therefore likely to be driving population declines, assuming that the mortality estimate is representative of historical years. However, there are a number of biases that are likely to have influenced this assessment and therefore the degree to which the PBR results can be used for defining management targets.

Uncertainty in the precise PBR parameter values created considerable uncertainty in the annual threshold level of sustainable anthropogenic mortality. Given this uncertainty it is recommended that the threshold levels not be used for defining management targets. Nevertheless, despite this uncertainty the sensitivity analysis shows that fisheries-related mortality greatly exceeds the sustainable limit irrespective of the parameter values used. However, the PBR analysis also assumes that the population is closed. As noted in chapter three, recent coastal sightings of dolphins along with significant seasonal changes in abundance question the degree to which the Karnaphuli-Sangu rivers population is indeed an isolated population. Current evidence from numerous historical coastal surveys suggests that it's unlikely there is a significant population of Ganges River dolphins in coastal waters during and therefore abundance does not greatly exceed the current best estimate. However, coastal survey effort has largely been constrained to the winter and late autumn seasons and so there is still some uncertainty with regards to the level of movement at other times of the year. At present there is not enough evidence to establish the likelihood that the population is in fact open and the level of movement between subpopulations. While data from a few surrounding regions (i.e. the Indian Brahmaputra and Bangladesh Sundarbans; Wakid and Braulik, 2009; Mahabub *et al*., 2012) suggest that mortality rates are just as high elsewhere, an absence of abundance and mortality data from the Ganges, Meghna and Bangladesh-part of the Brahmaputra make inferences on the sustainability of fisheries-related mortality in surrounding areas, incomplete.

While the accuracy of the mortality estimate is also questionable, the weight of evidence suggests that mortality was underestimated and so also the degree by which mortality is unsustainable. Where possible the survey design incorporated procedures for reducing biases associated with informant recall, reliability and species identification (e.g. limiting the time period over which informants were asked to recall bycatch events; checking informants could identify target species). Evidence suggests that informants were not responding randomly to questions on bycatch events because interview data from the Sundarbans and Brahmaputra show similar seasonal and mesh size patterns (Mahabub *et al*., 2012; M. Datta *pers. comm*. 2014). However, two major sources of bias could not be accounted for and are likely to have negatively biased the final estimate of mortality: a) the interviewed fishers were a sample from the wider population, though the data suggest the sample incorporated the majority of active winter fishers, and b) it is likely that fishers under-reported bycatch and mortality levels. Under-reporting of harvesting/ poaching levels is common in situations where the species is protected (e.g. Turvey *et al*., 2013). While the interviews revealed virtually no awareness of the laws protecting dolphins, unintentional killing of animals is forbidden by Islamic and Hindu laws and therefore may be considered a 'taboo' subject resulting in an unwillingness to discuss these events. The low proportion of bycatch events that resulted in death may be seen as further indication of informant under-reporting. However, in the absence of data to assess survival rates from gill net entanglement it is not possible to determine whether the gap between bycatch and mortality arises from under-reporting or high bycatch survivability.

There is also uncertainty in the degree to which the annual mortality estimate is indicative of previous years. The reported decline in the use of large-mesh gill nets suggests that bycatch rates may have decreased. Moreover, there has been a decline in the use of dolphin products for medicinal purposes with some informants reporting that they no longer hunt dolphins as a decrease in abundance means they are more difficult to catch. Conversely, informant reports of increasing fishing effort caused by the growing human population, and a decline in river depth suggest that bycatch and mortality incidents could be increasing. Without data on the inter-annual variability of fisheries-related mortality between 1999 and 2012, it is difficult to establish whether a significant decline would be expected.

5.5.3. Opportunities for bycatch mitigation

5.5.3.1. Local awareness of legislation protecting Ganges River dolphins

In the Bangladesh Sundarbans significant efforts have been carried out to generate awareness on the status of the Ganges River dolphin and the national laws that prohibit the killing of this species (WCS Bangladesh Cetacean Diversity Project, 2013), though it is not yet known how effective these measures have proven in terms of reducing intentional killing of dolphins. The results from this study show a near-absence of knowledge among the fishers of the Karnaphuli-Sangu rivers complex regarding the national law prohibiting the killing of this species. It is unlikely that fishers failed to understand the question, as responses to the question were frequently accompanied by the comment “there is no need for a law to protect *uchu mach* [Ganges River dolphin] as there is no demand for them”. Thirty five fishers did however report that according to religious law (Hindu) it is illegal to kill a species without cause.

The two fishers who were aware of a law lived in the same settlement on the Lower Sangu River and had been interviewed previously in 2004 by researchers from Chittagong University during a study looking at the feasibility of a protected area in the Lower Sangu River (Ahmed, 2004). During the interview by Chittagong University, the informants were told it was illegal to kill *uchu mach* but further questioning revealed that they did not appear to know of the implications of the law (i.e. imprisonment). Furthermore, knowledge of the law does not appear to have been shared with other community members of the same settlement, or neighbouring settlements as both killings in the last year occurred in neighbouring settlements and informants appeared very comfortable discussing the nature of these events with the interview teams. In the report on the findings of the study carried out by Chittagong University, it is noted that during a 2004 visit to the fisheries department office, the office “had no prior knowledge of the shushuks [i.e. another commonly used name for the Ganges River dolphin] in the Sangu” (Ahmed, 2004). Despite recommendations in 2004 by Chittagong University staff to the local fisheries department to increase local awareness of the laws prohibiting the killing of dolphins, the near-absence of knowledge on these laws suggest that no recent attempts have been made.

5.5.3.2. *Fishing and gear bans*

Limits or bans on gear use in artisanal fisheries are problematic as they impose restrictions on economically-impoverished communities (Davies, Beanjara and Tregenza, 2009). In some cases gears that are most bycatch-prone, yield the greatest income (Choudhary *et al*., 2006). The results suggest that while gill nets contribute significantly to overall bycatch, set bag nets pose a greater problem in terms of overall mortality rates. Furthermore, the results also suggest that set bag net fishers were under-represented in the interview sample and so the annual number of mortalities in set bag nets may be greater than that of gill nets. The Bangladesh set bag net fishery is one of the country's most important fisheries economically and in terms of employment (Khan *et al*., 1994; Nabi *et al*., 2011). There is considerable diversity in the types of set bag nets used within Bangladesh, from small (2 m wide) post larval set bag nets made of mosquito mesh, to the large (20 m wide) estuarine set bag nets (Khan *et al*., 1994; Nabi *et al*., 2011). Unfortunately the limited data on bycatch events prevented analysis of the factors that influence susceptibility to bycatch in this gear type. Given the significance of set bag nets in contributing to overall mortality, conservation efforts focused solely on limiting gill net use would ignore a large proportion of the overall mortality.

Time-area closures are a frequently employed measure for bycatch mitigation where bycatch patterns are temporally and spatially predictable (Murray, Read and Solow, 2000). However, the efficacy of closures is dependent on a thorough knowledge of these bycatch patterns (O'Keefe, Cadrin and Stokesbury, 2013; Murray, Read and Solow, 2000). Furthermore, closures are economically unsustainable where they overlap with areas of high fishing effort (Bordino *et al*., 2013). For many freshwater cetaceans, time-area closures may present an economically unfeasible option for conservation given the lack of data on dolphin bycatch patterns in different fisheries, and the well-documented spatial overlap between dolphins and artisanal fishing effort (Smith, 1993; Smith and Smith, 1998; Choudhary *et al*., 2006).

Mesh size restrictions and bans are another commonly used tool for mitigating bycatch (e.g. D'Agrosa, Lennert-Cody and Vidal, 2000). Development of alternative, less destructive fishing methods can be successful when carried out in conjunction with public participation and alternative sources of income (Dawson and Slooten, 1993). However, relative to small-mesh gill nets, large-mesh gill nets are associated with the capture of economically important species that may constitute a significant fraction of an artisanal fisher's annual income (e.g. Miranda, Agostinho and Gomes, 2000). The monsoon harvest of Hilsa contributes to 25% of all annual fish production in Bangladesh and is a large source of a fisher's annual income (Bala *et al*., 2014). Informants reported that fishing bans and mesh size restrictions have already been imposed in the study area to alleviate fishing pressure on small-sized Hilsa, locally known as *Jatka*. Rice is a commonly used form of compensation in Bangladesh for the loss of earnings during fishing bans (Ali *et al*., 2010). However, both the results from this study - and other studies - show that rice is widely regarded as an inadequate form of compensation for the loss of protein and earnings, and the distribution mechanism is poorly managed meaning the majority of fishers never receive any of the rice (Ali *et al*., 2010). Furthermore, more than half of the interviewed fishers in this study rely solely on fishing as a source of income and many are in debt to *Mohajan* (rich people) with high interest loans for buying fishing gear, so need to fish illegally during the bans to maintain loan repayments. Additionally, declining fish stocks and the poor economic situation, has forced a number of fishers to use illegal (i.e. *current jaal* and mosquito-mesh nets) and destructive fishing methods (i.e. poison fishing with DDT). These data highlight the significant economic barriers that are yet to be overcome before fishing bans and gear restrictions could effectively be used as a tool for mitigating bycatch of river dolphins in Bangladesh.

5.5.4. Future research

While this study has improved the evidence-base upon which to design effective conservation strategies for this population, it also highlighted a number of areas in which further research is needed. Due to a lack/ little variability in the data, it was not possible to investigate the influence of dolphin abundance and fishing effort on bycatch rates. Informal discussions with fishers suggest these factors exhibit considerable seasonal variability and therefore may help to explain the effect of season on bycatch rates. Similarly, insufficient data prevented an investigation of the factors predicting bycatch rates in set bag nets. To date, set bag nets have rarely been considered as a source of significant mortality for Ganges River dolphins. This may reflect a genuinely low level of mortality at other locations or may result from differences in the detectability of entanglements in each gear type. The nature of entanglements differs for both gear types: gill net entanglements typically involve the rostrum or fins getting caught in the mesh which can leave obvious external lacerations and abrasions. However, fisher's descriptions of entanglements in set bag net indicated that dolphins typically have fewer external marks as it is more common for the whole body to become trapped between the folds of the net. While set bag nets were responsible for significantly fewer bycatch events, they made a significant contribution to overall mortality therefore warranting future studies exploring the drivers of dolphin bycatch in this gear type.

While this study provides the first evidence that current fisheries-related mortality is unsustainable, uncertainty in the estimate of annual mortality precluded the use of the PBR for defining management targets. Given the inherent constraints of interviewing all fishers in the population or obtaining a random sample, deriving an accurate estimate of mortality is unlikely to be achievable. However, confidence in the minimum estimate of mortality could be improved by validation of the reported mortality incidents. Given the increasing use of interviews for collecting data on harvest/ poaching levels and the growing recognition of the biases associated with informant data, there is increasing use of social science techniques for validating informant data on sensitive topics (e.g. Randomised Response Technique, the unmatched-count technique, and triangulation; Solomon *et al*., 2007; St. John *et al*., 2010; Cross *et al*., 2013; Nuno *et al*., 2013; Gavin, Solomon and Blank, 2009; Nuno and St John, 2014). The potential utility of these techniques extends beyond validating informant data on bycatch events, but also better understanding the drivers of compliance with fishery regulations thus aiding informed policy decisions.

One of the major knowledge gaps affecting inferences on the historical and future sustainability of mortality, was the level of inter-annual variability in mortality. While there was evidence to suggest that bycatch levels are likely to have declined over the long-term, there was also evidence to suggest that bycatch rates may be increasing. Without data on the degree to which the mortality estimate is representative of historical years it is difficult to establish whether the population is declining. However, possible methods for addressing the knowledge gap on variability and trends in future mortality could include: 1) repeat interviews with informants, or a subset of informants, over multiple years; 2) having a sample of informants complete log books over multiple years in which they are asked to document the outcome (i.e. dolphin died, dolphin survived) of all bycatch events; 3) using mortality monitoring networks, such as the existing one in the Bangladesh Sundarbans (Mahabub *et al*., 2012), to document all river dolphin mortality incidents while standardising for monitoring effort and the detectability of mortality incidents. Based on the US Marine Mammal Stock Assessment guidelines, monitoring of bycatch may be required over a period of five years to obtain a more reliable estimate of mean annual mortality (NMFS, 2005). Efforts to address the knowledge gap on the future sustainability of fisheries-related mortality could improve confidence in management decisions focused on reducing fisheries-related mortality.

5.5.5. Conclusions

Interviews with local informants represent an important tool for addressing the significant knowledge gaps on cetacean bycatch in artisanal freshwater fisheries. While acknowledging that the Karnaphuli-Sangu rivers complex subpopulation may not represent an isolated population, interviews with the fisher community suggest that the current level of fisheries-related mortality is unsustainable. However, uncertainty in the level of movement between subpopulations and the PBR parameter values, limits the usefulness of the PBR threshold values for defining management targets. Furthermore, it is unclear from the current evidence base whether bycatch rates are increasing or decreasing. Assuming that the estimate of fisheries-related mortality is representative of current and future years, then the results of this study can contribute to developing informed policy decisions focused on bycatch reduction in gill net fisheries. Economic barriers and issues with law enforcement limit the likely efficacy of existing bycatch mitigation measures to this study system at the present time, emphasising the need for measures that account for the poor socioeconomic status of artisanal fisher communities.

Chapter 6. Discussion

The Upper Karnaphuli River

Freshwater cetaceans are one of the most threatened groups of mammals on earth (Reeves, Smith and Kasuya, 2000). The majority of species occupy densely-populated Asian river systems where they face growing threats associated with human development (Smith *et al*., 1998; Kreb *et al*., 2010; Smith *et al*., 2009; Braulik *et al*., 2014b; Ryan *et al*., 2011; Ahmed, 2000; Beasley *et al*., 2013; Zhao *et al*., 2008; Mei *et al*., 2012). However, limited resources and a lack of robust survey methods mean that basic information on river dolphin status and trends is lacking across large parts of their ranges. Subsequently, development of evidence-based conservation actions has been hindered for many populations.

6.1. Improving knowledge on the status of Ganges River dolphins in the Karnaphuli-Sangu rivers complex

6.1.1. Robust and cost-effective tools for assessing distribution and abundance

Robust estimates of abundance are often difficult to obtain given heterogeneous detection of individuals during surveys (Kéry and Schmidt, 2008; Kéry *et al*., 2009; Thompson *et al*., 2002). Data presented in chapter two and three demonstrate that combined visual-acoustic surveys can overcome many of the biases commonly associated with visual surveys of river dolphins, including: surveys of low density populations (i.e. the Upper Karnaphuli River; chapter two and three); surveys in waterways with considerable sighting biases (e.g. ships and heavily meandering river reaches; chapter two and three); missing dolphins not available for visual detection (i.e. availability bias; chapter two). Furthermore, as acoustic detection is not reliant on optimal sighting conditions, acoustic surveys may represent an opportunity to survey across a wider range of seasons, subsequently improving knowledge on temporal patterns of habitat use. Despite the demonstrated efficacy of acoustic surveys, uptake for freshwater cetacean monitoring has been slow due to perceived costs and technical skill requirements (Li *et al*., 2010). Data presented in chapter two and three demonstrate that combined visual-acoustic surveys represent both a cost-effective and robust method for estimating abundance. While the technical skill requirements exist, they may also present opportunities for regional collaborations.

6.1.2. Status of Ganges River dolphins in the Karnaphuli-Sangu rivers complex

While there is historical evidence to suggest that river dolphins have undergone a range decline in the Karnaphuli River following construction of Kaptai Dam in 1962 (Smith *et al*., 2001; Ahmed, 2000, 2004), I found no evidence of an increase or decrease in abundance between 1999 and 2012 (chapter three). The lack of a detectable negative long-term trend contrasts with the assessment of the sustainability of fisheries-related mortality (chapter five). Informant data presented in chapter four also support the conclusion that there has been a long-term decline in abundance, but uncertainty in the contribution of cognitive biases and the question format made it difficult to establish whether informants were reporting declines in dolphin abundance. As demonstrated in chapters three and five, there are a number of potential biases that are likely to have influenced both the long-term trends and the sustainability assessment. However, following a discussion of the relative likelihood of the biases affecting trends and the sustainability assessment (see chapter three and five), the following scenarios seem the most probable causes of the disparity between the long-term trends and the sustainability assessment: 1) the study population is significantly larger in size due to connectivity with surrounding rivers, particularly during the monsoon season, with lower levels of mortality in these other rivers; 2) historical levels of fisheries-related mortality were significantly lower than the current estimate resulting in no/ little change in population size. Given that the population is potentially isolated and that mortality may have recently increased to unsustainable levels, there is a need to address the likelihood of each of these outstanding biases. Addressing these knowledge gaps will require a mixed-methods approach for monitoring using standardised, robust methods to maximise the detection of short-term change (see 'Future Monitoring Schemes' in chapter three) and an assessment of the inter-annual variability in fisheries-related mortality (see 'Future Research' in chapter five).

6.1.3. Can local informants detect trends in abundance?

Interviews with local informants can yield accurate information on population trends, and constitute a low-cost tool for monitoring in areas where standard monitoring methods may be prohibitively expensive (Rochet *et al*., 2008; Turvey *et al*., 2013). However, informant recall of past conditions is subject to a range of cognitive biases that can affect the accuracy of responses. The comparison of informant-perceived trends and boat-based survey trends, exhibited varying levels of agreement. Given the limited sample size and range of potential biases, it was not possible to identify the specific factors influencing agreement. These data suggest that an informant's perception of abundance trends may be influenced by the magnitude of change, and variation in, informant engagement and frequency of interaction with dolphins. Furthermore, while viewed positively, the Ganges River dolphin has little economic importance among the sampled informants and so any potentially detectable trends may not have been deemed important to notice or remember. Evidence of 'shifting baseline syndrome' in the Upper Karnaphuli River emphasises the need for caution when interpreting informant-perceptions of trends/ abundance for rare or recently extirpated species.

6.1.4. Characterising the threats to freshwater cetaceans

Insufficient knowledge on the threats to a species can result in the use of inadequate or inappropriate conservation strategies (Wilson *et al*., 2007). The utility of interviews with local informants as a method for describing threats has been demonstrated in numerous studies (e.g. Brook and McLachlan, 2008; Turvey *et al*., 2013, 2014). Local informant interviews highlighted a number of potential significant threats to the dolphins in the Karnaphuli-Sangu rivers complex, and the presence of illegal activities. However, it was evident that the way in which knowledge is obtained influences an informant's perceptions of the significance of a particular threat (chapter four). For example, local media attention on the environmental impact of the Karnaphuli Paper Mill to aquatic wildlife may have led informants to perceive this as the most significant threat to Ganges River dolphins (chapter four). Conversely, religious beliefs may lead informants to downwardly bias the significance of threats such as intentional killing and bycatch (chapter four). Furthermore, informants may be limited in their ability to detect threats that yield limited visual cues, for example pollution (Turvey *et al*., 2013; chapter four). Given the scale of some of the threats identified here, these data suggest that conserving the Ganges River dolphin in the Karnaphuli-Sangu rivers complex may require actions on multiple threats.

6.1.5. Bycatch and the sustainability of fisheries-related mortality

Fisheries-related mortality is recognised as a significant threat facing all the world's freshwater cetacean species, but a lack of knowledge on patterns in fisheries bycatch and related mortality hinders the development of effective conservation actions for freshwater cetaceans (e.g. Beasley *et al*., 2007; Smith, Shore and Lopez, 2007; Turvey *et al*., 2007). However, evaluating the significance of threats to overall mortality is complex, particularly for poorly known species that face multiple interacting threats. In this study, I demonstrate that there are clear ecological patterns affecting the probability of dolphin bycatch and mortality. While an improved understanding of these patterns present opportunities for more targeted conservation actions, a lack of compliance with existing fishery legislations in the Karnaphuli-Sangu rivers (Ahmed, 2000; chapter five) suggests that a protected area in the Sangu River is unlikely to be successful in the absence of efforts to address issues with compensation schemes and capacity for enforcement. However, the unsustainable nature of fisheries-related mortality, emphasises the need for urgent actions to reduce accidental and intentional mortality. In the first instance, conservation actions may involve an awareness-raising programme to inform local communities of the laws prohibiting the capture and killing of dolphins.

6.2. Conservation opportunities for freshwater cetaceans

To date conservation efforts for freshwater cetaceans have largely focused on reducing accidental and intentional fisheries-related mortality (Choudhary *et al*., 2006; Sinha, Behera and Choudhary, 2010; Braulik, 2012; WCS Bangladesh Cetacean Diversity Project, 2013; Kreb *et al*., 2010). Efforts to mitigate both accidental and intentional mortality have commonly employed both protected areas and awareness-raising campaigns educating local communities on national and international laws protecting freshwater cetaceans.

Protected areas are a commonly employed conservation measure for alleviating threats to aquatic wildlife (Hoyt, 2005). Protected areas take many forms and are categorised on the basis of the level of protection they offer and on management goals (Dudley, 2008; Sciberras *et al*., 2013). The two forms of protected areas employed for freshwater cetaceans include: strict nature reserves (also referred to as no-take zones); and protected areas with sustainable use of natural resources (these may include spatially defined areas with fishing-gear bans and seasonal gear restrictions).

Gear bans and seasonal fishing bans have already been implemented for the Yangtze Finless Porpoise in the Yangtze River (Wang *et al*., 2010), and an ex-situ population in the Tian'e-Zhou Oxbow Reserve (Stone, 2010); Irrawaddy dolphins in the Mekong River in Cambodia (Beasley *et al*., 2013), the Ayeyarwady River in Myanmar (formerly known as the Irrawaddy River; Smith and Mya, 2007), Chilika Lagoon Reserve, India (D'Lima *et al*., 2013; Sutaria and Marsh, 2011), and the Mahakam River, Indonesia (Kreb, Budiono and Syachraini, 2007); the Indus River dolphin in the Sindh Dolphin Reserve, Pakistan (Pilleri and Zbinden, 1973; Braulik, 2006); the Ganges River dolphin in the Vikramshila Dolphin Sanctuary, India (Choudhary *et al*., 2006), and the Bangladesh Sundarbans (three dolphin sanctuaries established in 2011). There are no protected areas for the Amazon River dolphin, though efforts are currently underway to establish 30 protected areas in six South American countries specifically for this species (Gómez-Salazár *et al*., 2012). Bans have largely focused on restricting the use/eliminating gill nets, electro-fishing and small-mesh nets (i.e. mosquito-mesh nets; Kreb *et al*., 2010). In most instances protected areas have been developed and implemented in conjunction with programmes raising awareness of dolphin conservation, and laws prohibiting the killing of freshwater cetaceans (Braulik, 2006; Choudhary *et al*., 2006; Kreb *et al*., 2010; WCS Bangladesh Cetacean Diversity Project, 2013). There have also been attempts to develop alternative livelihoods for communities affected by the establishment of protected areas (Tian'e-Zhou Oxbow Reserve in China; Wang *et al*., 2010) and to develop wildlife and dolphin tourism opportunities (e.g. Chilika Lagoon in India, Sundarbans, Mekong River in Cambodia; (Choudhary *et al*., 2006; Sinha, Behera and Choudhary, 2010; Beasley, Bejder and Marsh, 2010; Kreb *et al*., 2010).

6.2.1. Evidence for the efficacy of protected areas

Evidence for the efficacy of protected areas for freshwater cetacean conservation is limited, due to their relatively recent establishment, and therefore limited time-series of data available for analysing abundance trends; and due to the use of methods that only partially account for detectability (Kreb *et al*., 2010). Furthermore, establishing the evidence for a given management activity (i.e. gear bans, seasonal closures, awareness-raising, law enforcement) is complicated by the fact that actions are often implemented simultaneously.

Repeat surveys of the Indus River dolphin in Pakistan employing tandem-vessel visual surveys indicate that there has been an increase in dolphin abundance since strict enforcement of anti-hunting laws in 1972 (Braulik *et al*., 2012a). While these observed increases are promising for protected areas elsewhere, the level of anthropogenic activity in the Indus River is considerably lower than for freshwater cetaceans in other locations (Braulik *et al*., 2012a). In India, repeat standardised direct counts of Ganges River dolphins also indicate possible increases in abundance in protected areas (Behera and Mohan, 2006; Sinha, Behera and Choudhary, 2010; Behera, 2006; Choudhary *et al*., 2006); however, the methods used cannot account for possible changes in group size and how this may have influenced detectability.

Monitoring the efficacy of measures for reducing intentional mortality is complicated due to a lack of robust methods for obtaining baseline measures of harvest. In the Mekong River in Cambodia and the Mahakam River of Indonesia, local NGOs have reported a decline in the number of annual mortalities and gill net entanglements since awareness-raising campaigns of laws prohibiting the killing of dolphins (Kreb *et al*., 2010); however, it is not known to what degree awareness-raising has resulted in informants under-reporting mortality and bycatch events.

6.2.2. Problems and solutions for protected area design and management

Protected areas rarely encompass the full geographical range of highly mobile species (Turvey *et al*., 2010a; Cheney *et al*., 2014). Effective reserve design therefore requires knowledge on: the spatial extent of species' movement and major threats (Tuck and Possingham, 2000; Wilson *et al*., 2007); the 'critical habitats' for species survival (e.g. important feeding and breeding grounds; Cañadas *et al*., 2005; Ashe, Noren and Williams, 2010; Williams *et al*., 2014); and how a species' behaviour influences vulnerability to threats (Williams, Lusseau and Hammond, 2009; Spitz *et al*., 2013). Despite considerable efforts to establish a network of protected areas for freshwater cetaceans, the literature highlights a range of issues that are likely to influence effective design.

6.2.2.1. Knowledge on species movement and critical habitats

Systematic biases in detectability, and visual-surveys restricted to seasons with optimal sighting conditions, limit knowledge on the spatial and temporal movement of individuals throughout the year. Combined visual-acoustic surveys represent a potentially useful tool for overcoming these knowledge gaps (chapter two). However, the limited detection range of acoustic data loggers and the difficulties in distinguishing click-train patterns between different species of small cetacean (chapter two) may limit the usefulness of this approach to narrow river systems containing a single species.

Additionally, data presented in chapter four suggest that local informant data could be used for identifying important breeding spots, sites that may not otherwise be detected without observational surveys across multiple seasons. However, the breeding sites for Ganges River dolphins identified in this study by local informants need validation with observational data.

6.2.2.2. Knowledge on threats and contribution to overall mortality

Evaluating the major threats to species can involve considerable resources through repeated observational surveys involving technical equipment and highly-trained staff (Aragones, Jefferson and Marsh, 1997). For most freshwater cetaceans, an inadequate knowledge of potential sources of mortality impede spatial management (Kreb *et al*., 2010). While interviews with local informants may be limited in their ability to rank the significance of threats because of varying knowledge sources, threat detectability or social desirability bias, they are a useful tool for describing the types of threats facing freshwater cetaceans, and may help identify threats that are otherwise undetected by local authorities, such as poison fishing (Turvey *et al*., 2013; chapter four and five).

While artisanal fisheries account for 95% of all the fishery manpower in the world, there are significant gaps in our knowledge on bycatch levels of aquatic wildlife in these fisheries (Chuenpagadee and Pauly, 2006; Moore *et al*., 2010). Monitoring the efficacy of measures for reducing intentional mortality is complicated due to a lack of robust methods for obtaining quantitative estimates of harvest (St. John *et al*., 2010; Cross *et al*., 2013). Knowledge gaps on the level and sustainability of freshwater cetacean fisheries-related morality have impeded the design of targeted conservation actions. Interviews with local informants may prove a useful tool for describing bycatch patterns in artisanal fisheries, and obtaining a minimum estimate of annual accidental and intentional mortality (chapter five). Direct questioning of informants (i.e. asking informants to describe annual bycatch) is problematic for obtaining accurate quantitative estimates of bycatch (particularly bycatch events resulting in intentional mortality; chapter five) given inherent under-reporting of sensitive topics (St. John *et al*., 2010; Gavin, Solomon and Blank, 2009). Furthermore, as knowledge of laws prohibiting the killing of freshwater cetaceans is disseminated among communities, it is likely that under-reporting is likely to increase. However, there are a number of promising tools commonly used in the social sciences, but increasingly used in conservation, for improving the accuracy of quantitative estimates of illegal behaviours including: the Randomised Response Technique, the unmatched-count technique, and triangulation (Solomon *et al*., 2007; St. John *et al*., 2010; Cross *et al*., 2013; Nuno *et al*., 2013; Gavin, Solomon and Blank, 2009; Nuno and St John, 2014).

6.2.2.3. *Law enforcement*

Even with adequate resources for implementing conservation strategies (such as protected areas), without user adherence to laws actions may prove ineffective at achieving conservation targets (Keane *et al*., 2008; Nicholson *et al*., 2012). A lack of compliance with local fishery laws and inadequate enforcement are common issues for management of freshwater cetaceans (Kreb *et al*., 2010). Effective management will require a better understanding of the factors that drive non-compliance. Interviews with local informants represent a useful tool for better understanding the issues surrounding law-breaking behaviour (chapter five).

6.3. Conservation of Ganges River dolphins in the Karnaphuli-Sangu rivers complex

To date, proposed conservation measures for the Karnaphuli-Sangu rivers complex subpopulation of Ganges River dolphins has focused on developing a protected area in the Lower Sangu River in a 45 km stretch from Dohazari to the river mouth (Smith *et al*., 2001; Ahmed, 2004). In 2004, a study was carried out to assess the feasibility of a protected area in this region, and to make recommendations for management. It was suggested that measures be taken to prohibit the use of *behundi jaal* (set bag nets) and *phasa jaal* (drifting gill nets), and that there be tighter enforcement of existing legislation prohibiting the use of small-mesh nets (Ahmed, 2004). While the data presented in chapter five supports actions limiting or regulating the use of these gear types, efforts should not be solely confined to the Sangu River. Furthermore, management may also need to consider threats from pollution (i.e. Karnaphuli Paper Mill, poison fishing with DDT), and declining river depth.

6.3.1. *Bycatch mitigation*

Fisheries-related mortality undoubtedly constitutes a significant threat to the long-term viability of the Ganges River dolphin subpopulation in the Karnaphuli-Sangu rivers complex. The evidence presented in chapter five suggests that management activities focused solely on mitigating bycatch in the Lower Sangu River would address only a fraction of the problem. However, significantly higher bycatch levels in the monsoon, in shallow river reaches, and in larger-mesh nets represent potential opportunities for more targeted actions, negating the need for complete bans on particular gear types.

6.3.1.1. Seasonal closures for gill nets

While there is already an annual 12-day ban on all fishing activity in October to preserve the Hilsa spawning stock, this is unlikely to significantly decrease annual bycatch of Ganges River dolphins. A ban on the use of the large-mesh gill nets during the monsoon across the entire study site could reduce dolphin bycatch by up to 60%.

6.3.1.2. Set bag nets

Given the significantly higher probability of mortality in set bag nets, further research is needed to understand the factors that influence bycatch and mortality patterns in this gear type. I suspect that given the considerably longer average soak-time of a set bag net compared to a drifting gill net (i.e. soak time of a set bag net = 6 hours; soak time of a drifting gill net = 2-4 hours), this may be the principal mechanism explaining the difference in mortality probability between the two gear types (chapter five). Given the documented economic importance of set bag nets (Nabi *et al*., 2011), bans may prove prohibitively expensive. However, the cost of compensating for the loss of income with a ban on set-bag nets may be offset by the fact that there are considerably fewer set bag nets in operation in the study area. While the lack of a representative sample prohibits any conclusions on the spatial distribution of bycatch, 67% (n=8/12) of all set bag net bycatch events in the 12-month period from October 2010 to October 2011 occurred in the Shikalbaha-Chandkhali Canal. A number of informants expressed concern over the use of set bag nets in the canal, as their size means they cover the entire channel so it is impossible for fish or dolphins to pass through the channel without swimming into the net.

6.3.1.3. Compliance with fishery laws

Restrictions on gear use, particularly gill nets and set bag nets, represent a significant loss of income for the fishing community of the Karnaphuli-Sangu rivers complex, losses that cannot be remunerated with the current compensation scheme. Based on the data presented in chapter five, the lack of compliance with existing legislation appears to be intricately connected to the poor economic situation within the fishery, a situation that is being further exacerbated by declining fish stocks.

Given the poor compliance with existing fishery regulations, inadequate compensation scheme (chapter five; Ali *et al*., 2010; Begossi *et al*., 2011), and a lack of resources within the fisheries department with which to enforce regulations (Ahmed, 2004), restrictions on gear use at the current time are unlikely to prove an effective measure for reducing/ eliminating dolphin bycatch and only likely to worsen the economic situation for many fishers. In the first instance, improving local knowledge of the national laws protecting the river dolphin may mitigate some if not all of the intentional mortality.

There is little empirical evidence for the success or failure of compensation schemes (Nyhus *et al*., 2005). However, based on the data presented in chapter five there are evidently a number of issues with the current scheme: 1) ensuring fishers receive compensation, and on time; 2) compensation not only for the loss of income for the ban duration, but subsequent months; 3) looking at alternative sources of compensation that allow fishers to continue loan repayments, thereby not exacerbating their debt problems. Even with adequate compensation schemes, people may continue to illegally exploit natural resources (Naughton-Treves, Grossberg and Treves, 2003), highlighting the need to simultaneously increase capacity to enforce laws. Limited capacity for law enforcement has been frequently cited as an issue affecting management of all freshwater cetacean populations (Smith *et al*., 1998; Reeves and Chaudhry, 1998; Reeves *et al*., 2003; Smith *et al*., 2004; WWF Nepal, 2006; Beasley, 2007; Kelkar *et al*., 2010; Kreb *et al*., 2010; Iriarte and Marmontel, 2013; Mintzer *et al*., 2013). Recent studies have found that where fisheries management is assigned to the local resource-users, perceptions of the benefits of regulations is improved, thereby increasing compliance with regulations (Cinner and Huchery, 2014). In India, Myanmar and Indonesia there are already examples of collaborative management (co-management) between fisher communities and government authorities where fishers have been employed as ‘river guards’. River guards are responsible for enforcing fishery laws, confiscating illegal fishing gear, and reporting dolphin mortalities and entanglements to the relevant authority (Kreb *et al*., 2010). Employing local ‘river guards’ may provide a low-cost alternative for increasing enforcement capacity (i.e. enforce fishery laws, detect destructive fishing practices such as poison fishing with DDT and the use of *current jaal*), monitor numbers of dolphin mortalities, and increase communication between local communities and the fisheries department.

6.3.2. Pollution

While threats acting independently of one another may pose little threat to a species, threats acting synergistically can significantly increase rates of decline (Brook, Sodhi and Bradshaw, 2008). Uncertainty in the nature of dependency between threats poses a significant challenge to the effective allocation of conservation resources, and therefore may require action on multiple threats simultaneously (Turvey *et al*., 2013). Studies investigating the impact of pollution on freshwater cetaceans are few, possibly due to the challenges that would be associated with addressing pollution in many Asian river systems. While few studies have examined the levels of varying pollutants in the Ganges River dolphin, one study has demonstrated that relative to small marine cetaceans this species has a reduced capacity to metabolise organochlorines, particularly DDT (Kannan *et al*., 1994). These findings are particularly worrying in light of the fact the Karnaphuli River is regarded as one of the most polluted rivers in Bangladesh, a problem that is exacerbated by the release of untreated effluent from Karnaphuli Paper Mill (rich in organochlorines, Ali and Sreekrishnan, 2001) directly into the headwaters of the river (Rahman and Kabir, 2010; The New Nation, 2014). The paper mill has been subject to a number of environmental audits by the Department of the Environment, which has imposed considerable fines and recommended establishment of an Effluent Treatment Plant (ETP). The prevalence of poison fishing using DDT is unclear based on data from local informants, but other studies show that this is not a problem exclusive to the Karnaphuli-Sangu rivers complex (Behera, Singh and Sagar, 2013). Informant data indicate that the majority of illegal poison fishing activity occurs at night to evade detection by local authorities, implying that it may be more widespread than my results suggest. Given the toxic effects of paper mill effluent and DDT not only on aquatic life but on humans (Ali and Sreekrishnan, 2001; Bhuiyan, Bhuiyan and Nath, 2009), actions to address these threats could have wide-ranging benefits.

6.3.3. Decreasing freshwater flow and salt-water intrusion

Management of freshwater cetaceans needs to take account of the increasing threat posed by declining freshwater flows and increasing salt-water intrusion into river systems (Smith *et al*., 2009). These issues present two potential problems for the Ganges River dolphin in the Karnaphuli-Sangu rivers complex: 1) loss of suitable habitat given the increasing intrusion of salt water into river systems; 2) increasing water-levels in the Karnaphuli River, which may require locks and barriers to protect land from flooding (Brammer, 2014). If the subpopulation of dolphins in the Karnaphuli-Sangu rivers complex is being sustained by net immigration, then physical structures in the river mouth would present a significant barrier to dispersal and access to potential coastal feeding grounds.

6.4. Conclusions

Insufficient resources for monitoring freshwater cetaceans mean that there are still significant gaps in our knowledge on the spatial and temporal patterns in distribution and abundance of many populations. These knowledge gaps hinder spatial management of populations, and prioritisation of those populations that are most in need of urgent conservation. Local informant interviews and combined visual-acoustic surveys represent two complimentary tools for improving knowledge on the status of freshwater cetaceans and the evidence-base upon which we can design and monitor conservation actions. Tools such as these are particularly important given the critical state of many freshwater cetacean populations across Asia and elsewhere. For many populations, threat status could deteriorate in the absence of efforts to develop adaptive management actions that account for both current threats and emerging threats associated with climate change. The last ten years have seen considerable efforts to initiate conservation efforts for many populations, the efficacy of which is yet to be proven. However, it is evident that the future viability of freshwater cetacean populations is intimately connected to the well-being of local communities, an area in which significant knowledge gaps remain. Efforts to impose gear bans and increase enforcement of fishery laws in the absence of simultaneous efforts to improve the socio-economic situation for local communities may create resentment towards management schemes and make conservation efforts ultimately unsuccessful. The challenge for conservationists and policy-makers will be to create economic and ecological win-win situations for both local communities and freshwater cetaceans, to ensure the continued survival of these highly threatened species within supportive local environments.

Appendix A

Table S1: Finalised questionnaire used for collecting informant data from the Karnaphuli-Sangu rivers complex.

For Interviewer Use Only		
Date	**_______________________ Interview number ______ Interviewer & translators names ____________________**	
Village name	_______________________ **Waypoint of village ___________**	
Interview location (e.g. at fisher house)	_______________________ **Gender of interviewee _____________**	
Religious affiliations of village	Hindu Muslim Buddhist Other (*please detail*)________________	
How was the interviewee selected?	Found Volunteered themself	**Comments on the interview (***please describe the informants behaviour***):**
Start time of interview		

1.	**How old are you?**
2.	**How many fishers live in this village?**
3.	**Have you always lived in this village?** *(Circle an answer)* Yes No (*Yes – go to question* 6. *No – go to question* 4.)
4.	**Where is the village that you used to live at?**
5.	**How long have you lived in this village?**
6.	**For each of the following** *(show them ID flashcards)*, **please describe:** 1 - Don't know Name: ____________ Lives in the forest/ sea/ river/ other __________ Does/ doesn't live in fishing range 2 - Don't know Name: ____________ Lives in the forest/ sea/ river/ other __________ Does/ doesn't live in fishing range

	3 - Don't know Name: ____________ Lives in the forest/ sea/ river/ other __________ Does/ doesn't live in fishing range 4 - Don't know Name: ____________ Lives in the forest/ sea/ river/ other __________ Does/ doesn't live in fishing range 5- Don't know Name: ____________ Lives in the forest/ sea/ river/ other __________ Does/ doesn't live in fishing range 6- Don't know Name: ____________ Lives in the forest/ sea/ river/ other __________ Does/ doesn't live in fishing range						
7.	**Do you still fish, or are you retired or have you changed occupation?** *(Circle an answer)* Still fishing Retired Changed occupation (*Still fishing – go to question* 10*. Retired or Changed Occupation – go to question* 8)						
8.	**When did you retire or stop fishing?**						
9.	**Why did you retire or stop fishing?**						
10.	**How many years have/were you been fishing?**						
11.	**What fishing gear do you use?**	**How many years have you been using this gear?**	**What months of the year do you use this gear?**		**How many days a week do you use this gear**	**How many other people do you fish with when you use this gear?**	**Where do you use this gear?**
	1.Phasha Jaal *Mesh*_________ *Material*______ *Length*________ *No. of nets*________		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	2.Ilish Jaal		Boishakh Joishtho	Kartik Ogrohayon			

	*Mesh*_________ *Material*______ *Length*________ *No. of nets*________		Asharh Srabon Bhadro Ashvin	Poush Magh Falgun Choitro			
	3.Geera Jaal		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	4.Hat Jaal *(Jaki, Jai)*		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	5.Borshi *No .of hook*_______ *Type (circle one):* **Long line** *Bora Macher* **Rod and line** *Bora Macher* **Chingri**		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	7.Behundi Jaal *Mesh*_________ *Length*________		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	9.Thirom Jaal *(Thela, Doka)*		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	10.Keski Jaal *(ask how it works)* *Mesh*_________ *Length*________		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			

	11.Deema Jaal		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	12.Ber Jaal		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	13.Hand Push Net		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	14.Dharma Jaal		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	15.Current Jaal *Mesh*_________ *Material*______ *Length*________		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	16.Poona Jaal *Mesh*_________ *Material*______ *Length*________		Boishakh Joishtho Asharh Srabon Bhadro Ashvin	Kartik Ogrohayon Poush Magh Falgun Choitro			
	Other _______________ _______________		Boishakh Joishtho Asharh Srabon	Kartik Ogrohayon Poush Magh			

			Bhadro Ashvin	Falgun Choitro			

12.	**Are there any fishing gears that you used to use but have now stopped using?** Yes No *(Yes – go to question 13. No – go to question 16).*
13.	**What are they?**
14.	**Why have you stopped using them?**
15.	**When did you stop using them?**
16.	**Is there a fishing ban on the river that you fish on?** Yes No Was for the last ______ year(s) *(Yes – go to question 17. No – go to question 19).*
17.	**What months of the year is/was the fishing ban?** Boishakh Joishtho Asharh Srabon Bhadro Ashvin Kartik Ogrohayon Poush Magh Falgun Choitro
18.	**What year did the fishing ban first start?**
19.	**Has the number of fish in the river increased, decreased, or stayed the same since you started fishing?**
20.	**Why?**
21.	**During a year, how far upstream and downstream do you fish?** *(Ask fishers to mark the range with the presence of towns, bridges, road, or give a kilometre range if possible)* **Upper limit =** **Lower limit =**
22.	**Do you have any other sources of income? If so, please describe.** Yes No Description _________________________________ *(No – go to question 24. Yes – go to question 23)*

<table>
<tr><td>23.</td><td colspan="2">What months of the year do you do this other job? (Circle an answer)

Boishakh Joishtho Asharh Srabon Bhadro Ashvin Kartik Ogrohayon Poush Magh Falgun Choitro

All the months that I am not fishing</td></tr>
<tr><td>24.</td><td colspan="2">Have you seen the uchu mach take fish from your nets?

Yes No</td></tr>
<tr><td>25.</td><td colspan="2">Are there more uchu mach in the area where you go fishing during Hemanta (late autumn) or Sheeth (winter)?

(No – go to question 28. Yes – go to question 26)</td></tr>
<tr><td>26.</td><td colspan="2">Why does the uchu mach number increase/decrease/ not change?</td></tr>
<tr><td>27.</td><td colspan="2">How do you know the number of uchu mach increases, decreases, doesn’t change?</td></tr>
<tr><td>28.</td><td colspan="2">Is there a season where you see more uchu mach in the river where you go fishing?

(No – go to question 30. Yes – go to question 29).</td></tr>
<tr><td>29.</td><td colspan="2">Why does the uchu mach number increase/decrease/ not change?</td></tr>
<tr><td>30.</td><td colspan="2">What are your feelings towards the uchu mach – do you like or dislike or are not bothered?</td></tr>
<tr><td>31.</td><td colspan="2">Why do you like/dislike uchu mach?</td></tr>
<tr><td>32.</td><td>Do you ever find uchu mach caught in your nets? (Circle an answer)

Yes No

(Yes – fill in the section opposite. No – go to question 33)</td><td rowspan="2">How many have you caught in your life? ___________________

How many have you caught in the last year? (please describe each event from the last year) ___________________

When did you/ they catch it? ____________________________

Size? ____________________________

Where? ________________________

Were you on your own at the time?</td></tr>
<tr><td>33.</td><td>Do you know of anyone else who has ever caught an uchu mach? (Circle and answer)

Yes No

(Yes – fill in the section opposite. No – go to question 35)</td></tr>
</table>

		_________________________ Fishing gear type? __________________________ Season? ____________________________ What part of the uchu mach was entangled in the net? ____________________________ What did you/ they do with the uchu mach – kill it, release it? ___________________ Was it dead or alive when it was found? ___________________________ Was the net or the uchu mach cut to release it from the net? ____________________________ Do you ever kill any uchu mach that you catch? ____________________________ If they kill the uchu mach, why? ____________________________
34.	**Why do you think uchu mach get caught in fishing nets?**	
35.	**Have you ever seen any dead uchu mach floating down the river or lying on the river bank?** Yes No *(Yes – go to question* 36. *No – go to question* 41*)*	
36.	**How many months or years ago did you find it?**	
37.	**What season or month did you find it?**	
38.	**Where was it when you found it?**	
39.	**Why do you think it died?**	
40.	**In your lifetime, how many dead uchu mach have you seen?**	
41.	**Would you say in the last ten years the number of uchu mach living in the river has stayed the same, increased, decreased or you don't know?** Increased Decreased Stayed the same Don't know (*Increased, Decreased, Stayed the same – go to question* 42*. Don't know – go to question* 44)	
42.	**Why has the uchu mach numbers increased/decreased/ not changed?**	

43.	**How do you know the number of uchu mach has increased/decreased/ not changed?**
44.	**When did you last see a live uchu mach?**
45.	**Have you, or do you know anyone else who has used uchu mach oil?** Yes No , but heard about it (*Yes, No but heard about it – go to question* 46*. No – go to question* 51)
46.	**What do you/ or the other person use uchu mach oil for?**
47.	**Is there a particular place and person that you buy uchu mach oil from?** (*If the informant sells the oil – go to question* 48*, otherwise go to question* 50).
48.	**How much do you sell the oil for?**
49.	**How much oil do you sell in a month?**
50.	**How much does uchu mach oil cost per millilitre?**
51.	**Do you of any law protecting the uchu mach?** No law Don't know of any law Yes there is a law_______________________
Time at end of interview:	
Additional questions regarding compliance with fishery laws and compensation schemes	
A1	**Do you fish during the ban?**
A2	**Why do you fish during the ban?**
A3	**Are there any fishing nets or other types of fishing gear that you are not allowed to use?**
A4	**Is there any compensation scheme (rice/ money) in place for the fishing ban?**
A5	**How often do you receive compensation?**
A6	**Are you pleased with the compensation?**
A7	**Why are you pleased/ not pleased with the compensation?**

Table S2: Finalised questionnaire (Bangla version) used for collecting informant data from the Karnaphuli-Sangu rivers complex.

শুধুমাত্র প্রশ্নকর্তার জন্য		
তারিখ	____________________সাক্ষাৎকার নাম্বার _______ প্রশ্নকর্তা এবং অনুবাদকের নাম ______________________	
গ্রামের নাম	__________________________ গ্রামের জিপিএস পয়েন্ট ____________	
সাক্ষাৎকার গ্রহনের স্থান (উদাঃ জেলের বাড়িতে)	__________________________ উত্তরদাতার লিঙ্গ______________	
গ্রামের প্রধান ধর্ম	হিন্দু ইসলাম বৌদ্ধ অন্যান্য (বিবরণ)__________________	
উত্তরদাতা নির্বাচনের পদ্ধতি	নির্বাচিত সাগ্রহে	মন্তব্য (উত্তরদাতার আচরণের বিবরন দিন(:
সাক্ষাৎকার শুরুর সময়		

1.	আপনার বয়স?
2.	এই গ্রামে সর্বমোট জেলের সংখ্যা কত?
3.	আপনি কী জন্ম থেকে এই গ্রামে বাস করেন ? (গোল দাগে উত্তর চিহ্নত করুন) হ্যাঁ না (হ্যাঁ – ৬নং প্রশ্নে যান ; না – ৪নং প্রশ্নে যান)
4.	আগে কোন গ্রামে বাস করতেন?
5.	এই গ্রামে কতদিন ধরে বসবাস করছেন?
6.	প্রতিটি নিম্নলিখিত প্রশ্নের (দেখান ফ্ল্যাশকার্ড আইডি), বিবরণ দিন: ১ - জানি না নাম: ______________ এর আবাসস্থল বন/ সমুদ্র/ নদী/ অন্যান্য ____________ মাছ ধরার এলাকায় বাস করেনা করে/ ২- জানি না নাম: ______________ এর আবাসস্থল বন/ সমুদ্র/ নদী/ অন্যান্য ____________ মাছ ধরার এলাকায় বাস করে/করে না ৩ - জানি না নাম: ______________ এর আবাসস্থল বন/ সমুদ্র/ নদী/ অন্যান্য ____________ মাছ ধরার এলাকায় বাস করে/করে না ৪ - জানি না নাম: ______________ এর আবাসস্থল বন/ সমুদ্র/ নদী/ অন্যান্য ____________ মাছ ধরার এলাকায় বাস করে/করে না ৫- জানি না নাম: ______________ এর আবাসস্থল বন/ সমুদ্র/ নদী/ অন্যান্য ____________ মাছ ধরার এলাকায় বাস করে/করে না ৬- জানি না নাম: ______________ এর আবাসস্থল বন/ সমুদ্র/ নদী/ অন্যান্য ____________ মাছ ধরার এলাকায় বাস করে/করে না

7.	আপনি এখন মাছ ধরেন, নাকি মাছ ধরা ছেড়ে দিয়েছেন অথবা পেশা পরিবর্তন করেছেন? (গোল দাগে উত্তর চিহ্নত করুন) মাছ ধরি ছেড়ে দিয়েছি পেশা পরিবর্তন (মাছ ধরি – ১০নং প্রশ্নে যান ; ছেড়ে দিয়েছেন অথবা পেশা পরিবর্তন – ৮নং প্রশ্নে যান)						
8.	কবে থেকে মাছ ধরা বন্ধ করেছেন?						
9.	কি কারনে মাছ ধরা বন্ধ করলেন?						
10.	আপনি কত বছর ধরে মাছ ধরছেন বা ধরেছেন?						
11.	কি দিয়ে মাছ ধরতেন?	কত বছর ধরে এটি ব্যবহার করছেন?	বছরের কোন কোন মাসে এটি ব্যবহার করেন?		সপ্তাহে কয়দিন ব্যবহার করেন?	কতজন একসাথে ব্যবহার করেন?	কোন এলাকায় এটি ব্যবহার করেন?
	১.ফাইস্যা জাল বুনানির ফাঁক__________ উপকরণ _______ দৈর্ঘ্য _________ জালের সংখ্যা_________		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	২.ইলিশ জাল বুনানির ফাঁক__________ উপকরণ _______ দৈর্ঘ্য _________ জালের সংখ্যা_________		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	৩.গিরা জাল		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	৪.হাত জাল (ঝাঁকি জাল)		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	৫.বড়শি		বৈশাখ	কার্তিক			

	বড়শির সংখ্যা________ প্রকার (একটিতে গোল দাগ দিন): সূতা বড়শি বড়মাছের লাঠি বড়শি বড় মাছের চিংড়ি		জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	৬.বেহুন্দি জাল বুনানির ফাঁক__________ দৈর্ঘ্য _________		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	৭.থিরুম জাল (ঠ্যালা,ডোকা)		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	৮.কেচকি জাল করে কাজ কিভাবে) (করুন জিজ্ঞাসা তা বুনানির ফাঁক__________ দৈর্ঘ্য _________		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	৯.ডিমা জাল		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	১০. ঘেরবেড়/জাল		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	১১.ঠেলা জাল		বৈশাখ জ্যৈষ্ঠ আষাঢ়	কার্তিক অগ্রহায়ণ পৌষ			

			শ্রাবণ ভাদ্র আশ্বিন	মাঘ ফাল্গুন চৈত্র			
	১২.ধর্ম জাল		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	১৩. কারেন্ট জাল বুনানির ফাঁক___________ উপকরণ _______ দৈর্ঘ্য _________		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	১৪.পোনা জাল বুনানির ফাঁক___________ উপকরণ _______ দৈর্ঘ্য _________		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
	১৫.অন্যান্য ____________________ ____________________		বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন	কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র			
12.	আর অন্য কিছু ব্যবহার করতেন মাছ ধরতে যা এখন আর ব্যবহার করেন না? হ্যাঁ না (হ্যাঁ – ১৩নং প্রশ্নে যান; না – ১৬নং প্রশ্নে যান)						
13.	কি ব্যবহার করতেন?						
14.	কেন সেটি ব্যবহার করা বন্ধ করলেন?						
15.	কবে থেকে ব্যবহার করা বন্ধ করলেন?						
16.	আপনি যে নদীতে মাছ ধরেন, সেখানে মাছ ধরার নিষেধাজ্ঞা আছে?						

	হ্যাঁ না ছিলোবছর _______________ গত , (হ্যাঁ – ১৭নং প্রশ্নে যান; না – ১৯নং প্রশ্নে যান)
17.	বছরের কোন কোন মাসে মাছ ধরা নিষেধ? বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র
18.	কোন বছর থেকে মাছ ধরার নিষেধাজ্ঞা জারি হয়?
19.	নদীতে মাছের পরিমান কি বেড়েছে ,কমেছে?আছে একই মত আগের নাকি ,
20.	কেন?
21.	মাছ ধরার জন্য প্রতি বছর উজানে বা ভাটিতে কতদূর যান? (দূরত্ব বোঝানোর জন্য জেলেকে নিকটবর্তী শহর, সেতু, রাস্তা, অথবা সম্ভব হলে কিঃমিঃ এ জিজ্ঞেস করুন) উজানের সীমা = ভাটির সীমা =
22.	আপনার আয়ের কি অন্য কোন উৎস আছে? থাকলে উল্লেখ করুন হ্যাঁ না আয়ের উৎস ____________________________________ (হ্যাঁ – ২৪নং প্রশ্নে যান; না – ২৩নং প্রশ্নে যান)
23.	বছরের কোন কোন মাসে অন্য পেশায় নিয়োজিত থাকেন? (গোল দাগে উত্তর চিহ্নত করুন) বৈশাখ জ্যৈষ্ঠ আষাঢ় শ্রাবণ ভাদ্র আশ্বিন কার্তিক অগ্রহায়ণ পৌষ মাঘ ফাল্গুন চৈত্র মাছ ধরা ব্যতিত অন্য সকল মাস
24.	উচু মাছকে আপনার জাল থেকে মাছ নিয়ে যেতে দেখেছেন? হ্যাঁ না
25.	আপনি যেখানে মাছ ধরেন সেখানে হেমন্তকালে নাকি শীতকালে বেশি উচু মাছ দেখা যায় ? হ্যাঁ না (হ্যাঁ – ২৮নং প্রশ্নে যান; না – ২৬নং প্রশ্নে যান)
26.	উচু মাছের সংখ্যা কমে/বাড়ে/অথবা একই থাকে কেন?
27.	আপনি কিভাবে বুঝতে পারেন যে উচু মাছের সংখ্যা কমে/বাড়ে/অথবা একই থাকে?
28.	এমন কোন মৌসুম আছে যখন মাছ ধরার সময় বেশি উচু মাছ দেখতে পান? হ্যাঁ না

	(হ্যাঁ – ৩০নং প্রশ্নে যান; না – ২৯নং প্রশ্নে যান)	
29.	উচু মাছের সংখ্যা কমে/বাড়ে/অথবা একই থাকে কেন?	
30.	উচু মাছদের আপনার কেমন লাগে – ভাল/খারাপ/ চিন্তা করি নাই	
31.	উচু মাছ আপনি কেন পছন্দ বা অপছন্দ করেন?	
32.	আপনার জালে কখন উচু মাছ ধরা পড়েছে? (গোলদাগে উত্তর চিহ্নত করুন) হ্যাঁ না (হ্যাঁ – ডান পাশের অংশের প্রশ্নের উত্তর দিন; না – ৩৩ নং প্রশ্নে যান)	আপনার জীবনে মোট কতগুলো ধরেছেন? ____________________ গতবছর কতগুলো ধরেছেন (দিন বর্ণনা ঘটনার প্রতিটি)? ____________________ কিভাবে ধরলেন/ তারা ধরলো? ______________________________ আয়তন? ______________________________ কোথায়? _________________________ আপনি সে সময় একা ছিলেন? ___________________________ কি ধরনের জাল ছিল? ____________________________ মৌসুম? ______________________________ উচুমাছের কোন অংশ জালে আটকা পড়ে? ______________________________ উচু মাছটাকে কি করলেন – মারলেন না ছেড়ে দিলেন? ____________________ উচুমাছটাকে যখন দেখলেন তখন কি বেঁচে ছিল না মৃত? _____________________________ উচু মাছটাকে ছাড়ানোর জন্য জাল কাটলেন না মাছের বাঁধা অংশ কাটলেন______________________________ উচু মাছ ধরা পরলে মেরে ফেলেন? ______________________________ কেন মারেন? ______________________________
33.	এমন কাউকে চেনেন যার জালে উচু মাছ ধরা পড়েছে? (গোলদাগে উত্তর চিহ্নত করুন) হ্যাঁ না (হ্যাঁ – ডান পাশের অংশের প্রশ্নের উত্তর দিন; না – ৩৫ নং প্রশ্নে যান)	
34.	উচু মাছ কি কারনে জালে ধরা পড়ে ?	

35.	আপনি কি কখন মরা উচু মাছ দেখেছেনযেতে ভেসে বা পাড়ে নদীর -? হ্যাঁ না (হ্যাঁ – ৩৬নং প্রশ্নে যান; না – ৪১নং প্রশ্নে যান)
36.	কত দিন আগে (মাস/বছর) দেখেছেন?
37.	কোন মৌসুম ছিল তখন?
38.	কোথায় দেখতে পেলেন?
39.	কি কারনে মারা গেল বলে আপনি মানে করেন?
40.	আপানার জীবনে কতগুলো মৃত উচু মাছ দেখেছেন?
41.	আপনার মতে গত দশ বছরে নদীতে উচু মাছের সংখ্যা কেমন আছে - বেড়েছে কমেছে একই আছে জানি না (বেড়েছে, কমেছে, একই আছে – ৪২নং প্রশ্নে যান. জানি না – ৪৪নং প্রশ্নে যান)
42.	আপনার কেন মনে হয় উচু মাছের সংখ্যা বেড়েছে/ কমেছে/ একই আছে?
43.	আপনি কিভাবে বুঝলেন উচু মাছের সংখ্যা বেড়েছে/ কমেছে/ একই আছে?
44.	শেষ কবে আপনি জীবিত উচু মাছ দেখেছেন?
45.	আপনি অথবা আপনার চেনা কেউ উচু মাছের তেল ব্যবহার করেছেন? হ্যাঁ না না, কিন্তু এর কথা শুনেছি (হ্যাঁ , না, কিন্তু এর কথা শুনেছি – ৪৮নং প্রশ্নে যান; না – ৫১নং প্রশ্নে যান)
46.	আপনি বা অন্যরা উচু মাছের তেল কেন ব্যবহার করেন?
47.	আপনি কি বিশেষ কোন স্থান বা ব্যক্তির কাছ থেকে উচু মাছের তেল কিনেন? (উত্তরদাতা তেল বিক্রেতা হল- ৪৮নং প্রশ্নে যান; নতুবা – ৫১নং প্রশ্নে যান)
48.	কত টাকায় তেল বিক্রি করেন?
49.	মাসে কি পরিমান তেল বিক্রি করেন?
50.	প্রতি মিলিমিটার উচু মাছের তেলের দাম কত?
51.	উচু মাছ রক্ষায় কোন আইন আছে বলে আপনার জানা আছে? কোন আইন নাই আমার জানা নাই হ্যাঁ আইন ,আছে ____________________________
52.	সাক্ষাৎকার গ্রহন শেষের সময় ____________________________

Appendix B

Figure S1: Ganges River dolphin mortality discovered at 10 pm on the 13th of November in the Halda River near the Sattar Ghat Bridge.

Figure S2: Ganges River dolphin mortality discovered at 11 am on the 14th of December at the confluence of the Shikalbaha-Chandkhali Canal and Lower Karnaphuli River. The image depicts the dolphins being drained of oil which, according to the fisher who caught it, will be sold for medicinal purposes.

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