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Searching for trends in river dolphin abundance: Designing surveys for looming threats, and evidence for opposing trends of two species in the Colombian Amazon

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ABSTRACT

Rivers worldwide, particularly in tropical regions, support multiple human uses that can threaten water security and cause species decline. Some tropical rivers are home to obligate freshwater cetaceans (river dolphins) that are vulnerable to exploitation and to upstream and downstream habitat degradation due to limited dispersal opportunities. Assessing vulnerability is complicated by difficulty in reliably estimating abundance, due to the animals' cryptic nature and complex, dynamic habitat. We compared density estimates from surveys conducted in 1993, 2002 and 2007. Surveys were not part of a coordinated monitoring plan and thus were conducted using slightly different methods in different months, which complicated statistical inference. We used information from the most recent survey to account for bias and uncertainty in earlier estimates and used bootstrap and Bayesian approaches to estimate trends, conditional on a plausible range of process variance associated with seasonal movements. For *Inia*, probability of decline was >0.75, even under the highest seasonal movement levels considered. For *Sotalia*, there was a >0.75 probability of population increase. There are 151 proposals pending in the Amazon for large (>2 MW) hydroelectric developments that would fragment habitat, and reports suggest that *Inia* is experiencing illegal killing for fish bait. In this context, our population trend estimates are cause for concern, but improved monitoring is needed to more reliably assess population status. Based on lessons learned from our analysis, future surveys will be standardized in terms of timing (conducted during the transitional water season) and methodology (using our most recent field protocols) to minimize confounding factors and provide more robust inference about population trends. We provide recommendations for ways to distinguish seasonal movements from annual population trends to guide Amazon river dolphin conservation. Until then, two interpretations exist: either *Inia* is declining, or existing information cannot detect declines unambiguously without additional surveys. Neither explanation bodes well, given the myriad anthropogenic stressors Amazon river dolphins face.

1. Introduction

Rivers worldwide are in crisis; water security for 80% of the human population is considered at high risk, habitats associated with nearly 65% of global river discharge is considered under moderate to high threat, and rates of species decline and losses are much higher than in many other types of ecosystems (Dudgeon et al., 2006; Vörösmarty et al., 2010). In the tropical regions that are home to obligate freshwater cetaceans, human use of natural resources is particularly reliant on access to rivers (Sanderson et al., 2002). This creates a situation in which human activities are spatially concentrated along river banks, animals are restricted spatially in terms of their ability to shift their distribution to mitigate pressure from anthropogenic stressors, and the overlap of spatially aggregated species and stressors can have dire consequences for endangered species (Williams et al., 2009). With limited option to disperse, species that live in human-dominated riverine habitats are at the mercy of both upstream and downstream effects, including pollution, dam construction, overfishing and indirect effects of logging (Dudgeon, 2011; Dudgeon et al., 2006).

River dolphins are a particularly vulnerable group of aquatic mammals that are situated along a spectrum of human-induced perturbation in large tropical rivers of Asia and South America (Smith and Reeves, 2012). As a consequence of incidental mortality caused by fishing gear and effects of habitat degradation, the baiji or Yangtze river dolphin (*Lipotes vexillifer*) is now likely extinct (Turvey et al., 2007), and the Yangtze finless porpoise (*Neophocaena asiaeorientalis* ssp. *asiaeorientalis*)

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is in serious decline (Mei et al., 2012; Zhao et al., 2008). The biodiversity crisis unfolding in the Yangtze is one of the most serious cases of river system demise caused by a multitude of human activities, but many less-impacted river systems with currently high biodiversity face uncertain futures as diverse threats loom. For example, numerous additional dams have been proposed for the main stem of the Mekong River, which could have dire consequences for threatened fishes (Dudgeon, 2011) and the Mekong subpopulation of Irawaddy dolphin *Orcaella brevirostris* (IUCN Red List assessment; (Beasley et al., 2013)). River dolphin populations that were once considered healthy in the now highly modified Indus and Ganges river basins, such as Indus River dolphins (*Platanista gangetica minor*), are facing emerging threats that are difficult to assess quantitatively, including new dam construction projects and habitat destruction as growing human populations encroach on increasingly remote areas (Braulik, 2006; Braulik et al., 2012). In addition to unintentional or sub-lethal effects of human activities, some river dolphin populations in the western Brazilian Amazon are facing new threats in the form of direct exploitation by humans for bait in lucrative fisheries (Iriarte and Marmontel, 2013; Mintzer et al., 2013; Robards and Reeves, 2011).

At first glance, the issues facing river dolphins may appear to be no different than many other species, given the current global biodiversity crisis (Myers et al., 2000). But in addition to all of the above-mentioned ecological and anthropogenic risk factors, freshwater cetaceans also happen to be especially difficult to study. This makes it difficult to design monitoring programs to identify when mitigation measures are succeeding, failing or even necessary. The International Whaling Commission has noted that conservation of freshwater cetaceans is hindered by lack of reliable information on abundance or trends, resulting from difficulty in designing surveys for cryptic species in geographically complex habitats (International Whaling Commission, 2001). A variety of decision rules exist to set sustainable limits to human-caused mortality (Dillingham and Fletcher, 2008; Moore et al., 2013; Wade, 1998; Williams et al., 2008), but they all hinge on good estimates of abundance. River dolphin extinction is not always preceded by an obvious range contraction or clear-cut evidence of habitat fragmentation (Huang et al., 2012; Turvey et al., 2010a). River dolphins have been proposed as indicators of the level of ecosystem degradation in large tropical rivers of Asia and South America (Gomez-Salazar et al., 2012a; Turvey et al., 2012), which necessitates a reliable system for monitoring abundance. There are plans for 151 new large (i.e., >2 MW) dams on the Amazon over the next 20 years (Finer and Jenkins, 2012). The potential for habitat fragmentation is large, and baseline information is needed to assess risks associated with dam construction.

Four freshwater dolphin species are found in the Amazon River basin: the pink river dolphin (also called boto in Brazil and bufeo elsewhere) that is composed of two subspecies (*Inia geoffrensis geoffrensis* and *Inia geoffrensis humboldtiana*); the Bolivian river dolphin (*Inia boliviensis*); the Araguaian river dolphin (*Inia araguaiaensis*); and the tucuxi (*Sotalia fluviatilis*) (Borobia et al., 1991; da Silva, 1994; Hrbek et al., 2014). *I. geoffrensis* and *S. fluviatilis* are listed by the IUCN as Data Deficient, partly due to lack of population data. The status of *I. boliviensis* and *I. araguaiaensis* has yet to be established. Cultural taboos against killing pink river dolphins throughout much of the dolphins' range has historically protected them from direct exploitation (Leatherwood and Reeves, 1994). In the last decade or so, it has become apparent that pink river dolphins are being killed in large numbers: (i) for use as bait in the lucrative "piracatinga" [pirate catfish] fishery (Iriarte and Marmontel, 2013; Loch et al., 2009; Mintzer et al., 2013; Pinto de Sá Alves et al., 2012)); and (ii) because fishermen regard them as competitors for fish or as a source of damage to fishing gear (Reeves et al., 2011). Given the cryptic nature of poaching (i.e., mortality goes unreported and the carcasses may be consumed by piracatinga), it is difficult to know whether *Inia* or *Sotalia* is hit harder by this source of anthropogenic mortality, but Brazilian research suggests that *Inia* are more likely than *Sotalia* to be targeted (da Silva and Martin, 2000; Iriarte and Marmontel, 2013). Information on *Sotalia* status is needed, because the riverine and coastal forms have only recently been recognized as separate species (Caballero et al., 2007). In terms of habitat degradation, it is important to note that some of the world's largest dam proposals are proposed throughout Amazonia. Robust abundance estimates are needed for both species to inform environmental assessments. There is an urgent but limited-time opportunity to establish monitoring programs now that can provide baseline estimates of population abundance, against which future surveys can quantify and ideally mitigate impacts of planned activities.

Given relatively low levels of precision typical for cetacean abundance estimates, only steep declines have a reasonable chance of being detected over a short (15-year) time period based on typical survey schedules (e.g., once every several years) and using conventional regression analysis techniques for estimating trends (Taylor et al., 2007). Even for shallow-diving, coastal species, declines that would warrant a vulnerable listing under the IUCN Red List classification would go undetected ~70% of the time (Schipper et al., 2008). Because statistical precision in wildlife abundance estimates is driven in part by sample size and survey effort, this simple summary of statistical power may be optimistic for regions of the world where funding is severely limited. In the face of uncertainty as to whether protected wildlife populations are declining, three precautionary suggestions have been made. First, one can make management decisions based on *any* evidence of a decline from point estimates, even when $P > 0.05$ (Taylor et al., 2007). Secondly, if population assessments are considered unfeasible, simple decision rules in the form of reference points can be used to limit annual anthropogenic mortality to a level that should prevent a population from falling below a defined management target (Moore et al., 2013; Taylor et al., 2000; Wade, 1998). Finally, Bayesian hierarchical models can be used to improve inference about trends from sparse or imprecise data (Moore and Barlow, 2011; Moore and Barlow, 2013).

Here we report three sets of abundance estimates for *Inia* and *Sotalia* in the Colombian Amazon from 1993 to 2007, in largely the same study area, including previously unpublished survey data from 2002. We describe an attempt to assess trends but note the limitations of doing so given available information. We assessed the likelihood that either of these species has declined in the region over the last 20 years, after accounting for the fact that surveys were conducted in different seasons (see Methods). We are particularly concerned with *Inia*, which has recently been subjected to direct killing for bait in parts of the Brazilian Amazon (Iriarte and Marmontel, 2013; Mintzer et al., 2013). The survey data were collected from three independent field expeditions, rather than from a coordinated monitoring program, so we used Bayesian methods to estimate annual trends conditional on a range of priors for process variance to account for seasonal movements. We knew at the outset that it would be impossible to infer trends and population status in a robust and reliable way, given the number of factors that changed across the three surveys and lack of information on seasonal movement patterns of *Inia* and *Sotalia* in the region. Instead, our objective was to account for as many confounding factors as possible, given best available information, to allow a reasonable exploration of the possibility that *Inia* has declined, given recently raised concerns about poaching of this species for bait. Our expectations for this exploratory analysis were modest, because our inference is necessarily conditional on some important assumptions about seasonal movements for which we had to rely on plausible bounds instead of empirical estimates. Lessons learned through the course of this analysis will allow us to make time-sensitive recommendations about new data to collect, to improve Amazon river dolphin monitoring programs, and standardize data analysis methods, which will improve our ability to assess status and trends in the future. Our overarching motivation was to inform work plans that will allow future, dedicated studies to assess likely impacts of the construction of "mega-dams" in the Amazon Basin on river dolphin populations.