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A preliminary methodology to characterize gillnet fleets in the Indian Ocean using satellite imagery: a case study on Pakistan

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Abstract: Current data on cetacean bycatch in the Indian Ocean is extremely limited, but available information suggests that bycatch rates in gillnets may be unsustainable for some species, particularly in drift gillnets. Many drift gillnet fleets operating within the Indian Ocean Tuna Commission (IOTC) area of competence are comprised of relatively small vessels and are poorly documented by national management agencies. This contrasts with purse seine and pelagic longline fleets operating in this region, for which target catches and bycatches are relatively well documented. To help address knowledge gaps regarding the drift gillnet fleet, we are working to obtain information on drift gillnet vessels from several IOTC Contracting Parties, particularly those fisheries occurring in the northern Indian Ocean: Oman, Pakistan, India, Sri Lanka, Indonesia, and Iran. We propose to develop preliminary estimates of the size of the tuna drift gillnet fleet in these countries by using satellite imagery and machine learning to count vessels in relevant ports, characterize the fleet, and assess spatial distribution. Using independent estimates of bycatch and catch data reported to IOTC, we hope to create bycatch estimates for the fleets, where possible. Our efforts are in the early stages, and we are currently focused on fine-tuning our specific questions to answer with the satellite imagery and machine learning workflows. We seek feedback on our proposed methods to: 1) better understand the drift gillnet fleet in the Indian Ocean, particularly in regions where large drift gillnet fleets are known to operate; and 2) gauge feasibility, pitfalls, and areas for collaboration for the proposed methodology, particularly the analysis of satellite imagery to characterize gillnet fleets. Our work is relevant to both the IWC Bycatch Mitigation Initiative and to the work of the IOTC's Working Party of Ecosystems and Bycatch. We plan to combine this new information on fleet size and operation with a concurrent gap analysis of information on cetacean bycatch in these countries to characterize cetacean by-catch in these countries. We hope this work will assist the IOTC and IWC BMI in meeting some of their agreed steps following a joint meeting in September 2020.

Key takeaways

- Knowledge gaps on cetacean bycatch in fisheries managed by IOTC are widespread, including for tuna drift gillnet fisheries, which are prevalent amongst many IOTC Contracting Parties.

- Many of these fishing vessels lack vessel monitoring systems (VMS), observer coverage, and reporting that provides information on catch, effort, and bycatch on industrial fisheries.
- In light of the dearth of information and fisheries monitoring, surveillance, and enforcement, new methods are required to obtain information on cetacean bycatch.
- We propose to use satellite imagery to count and characterize gillnet fleets of IOTC Contracting Parties, which will inform coarse bycatch estimates.
- We propose to conduct an initial pilot study in Pakistan to test our methodology, with the aim to create a scalable and repeatable methodology for other fisheries and locations.
- We proposed to use imagery from Maxar's GeoEye and Worldview 2 and 3 and the Planet "Dove" constellation to quantify and characterize Pakistan's semi-industrial tuna fleet. WWF-Pakistan will ground truth this information in Port by counting vessels and conducting port surveys.
- We will estimate bycatch using unanalyzed crew-based observer coverage data from WWF-Pakistan.
- Co-authors are in early stages of this work, and welcome and seek feedback on the methodology.

Introduction

Background

Bycatch is the leading threat to marine mammal populations (Lewison et al., 2004; Lewison et al., 2014), with gillnet fisheries responsible for the largest portion of this mortality (Read et al. 2006; Brownell et al., 2019). In the Indian Ocean, the bycatch of small cetaceans is pervasive in poorly regulated drift gillnet fisheries (IWC 2019; Anderson et al., 2020), but knowledge gaps in this region are particularly acute. Anderson et al. (2020) estimated that over 4 million cetaceans have been killed in Indian Ocean drift gillnet fisheries since 1950 and roughly 100,000 during 2004-2006. However, the management body charged with regulating tuna fisheries in the region — the Indian Ocean Tuna Commission (IOTC) — has reported only 76 incidents of cetacean bycatch since 1996, none in gillnet fisheries (IOTC-IWC, 2020). This dramatic mismatch of information is indicative of widespread underreporting and monitoring. Thus, there is an urgent need to better understand the occurrence, magnitude, and impacts of cetacean bycatch in the Indian Ocean, particularly in drift gillnet fisheries.

Tuna drift gillnet fisheries provide a critical source of protein and income in the region. Nonetheless, bycatch in these fisheries is often poorly monitored, and the use of drift gillnets continues to expand in the Indian Ocean (Temple et al., 2018; Roberson et al. 2019). Gillnets are commonly used to catch tuna in the Indian Ocean and are the major gear type used in the northern Arabian Sea (Moazzam 2013; Anderson et al. 2020). Currently, drift gillnet fishing contributes approximately 35 percent of IOTC's nominal catches (Aranda 2017; Anderson et al., 2020). Since 2000, 29 IOTC Members have reported some level of gillnet catch to the IOTC (IOTC 2021). Of these, Iran is by far the largest gillnet fishing nation in the IOTC, followed by Indonesia, India, Sri Lanka, Pakistan, Oman, and United Arab Emirates, respectively (Moazzam 2013; Aranda 2017; Anderson et al., 2020; IOTC 2021). Few of these countries report data other

than nominal catches, creating widespread data gaps on fishing effort and bycatch in the region (Aranda 2017). Drift gillnet fishing is increasing in the region, likely due to low operational costs (Aranda 2017).

In general, existing definitions for drift gillnet vessel classifications in the IOTC are confusing. Drift gillnet fishing in the IOTC can be classified into three broad categories, largely based on vessel length overall (LOA): artisanal, semi-industrial, and industrial (Aranda 2017). In the IOTC Convention Area, tuna drift gillnet fisheries are primarily comprised of semi-industrial gillnet vessels. There is no clear definition of this vessel type, but they are generally understood to be motorized vessels from 15 to 24 m in length, fishing within EEZs and on the high seas (Moreno and Herrera 2013). This ambiguous definition renders semi-industrial vessels exempt from some IOTC conservation and management measures (CMMs). For example, the Regional Observer Program (IOTC Resolution 11-04) does not pertain to the vessels under 24 m and the CMM focused on cetaceans (IOTC Resolution 13-04) exempts vessels from following the measure if under 24 m in length and fishing within their own EEZ.

Pakistan is one of the leading gillnet fishing nations within the IOTC (Figure 1). Nominal catch data reported to the IOTC indicates that Pakistan's tuna catch has been increasing since 1950 (Figure 1). Total cumulative catches in Pakistani gillnets were about 2 million tons from 1950-2019, with an annual production of about 75,000 tons in recent years (2015-2019) (IOTC 2021). Khan (2018) estimated that 820 pelagic drift gillnet vessels operated in 2017 in Pakistan, which includes 200 small-scale inshore vessels and 620 larger vessels fishing offshore. It is believed that some vessels in Iran and Pakistan are registered in both countries (Moazzam 2013). The length of drift gillnets employed in Pakistan ranges from 3 to 7 km (IOTC 2019) and vessels range in size, but can reach 15-30 m LOA (WWF Pakistan, personal communication). Fishing grounds range from shelf waters to deep oceanic waters including in Areas Beyond National Jurisdiction, particularly in Pakistan and Iran (Kiszka et al. 2021; in revision).

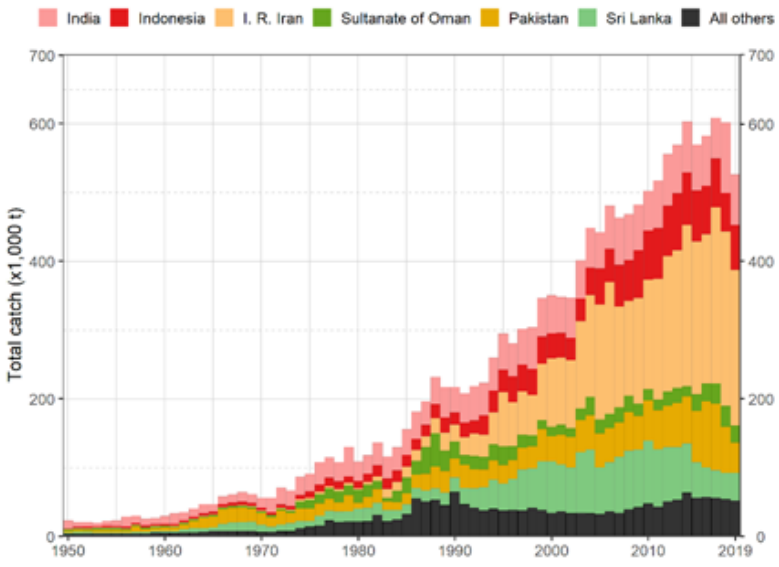

Figure 1. Nominal catch by IOTC drift gillnet fleets since 1950

Bycatches of cetaceans are known to occur frequently in semi-industrial tuna drift gillnet fisheries in Pakistan (IWC 2019). Preliminary estimates suggest that 8,411 (SE=1,057) cetaceans are taken annually as bycatch in Pakistani tuna drift gillnet fisheries (Kiszka et al. 2021, in revision). Cetacean species taken commonly as bycatch include spinner dolphins (*Stenella longirostris*), bottlenose dolphins (*Tursiops truncatus*), common dolphins (*Dephinus delphis*), Risso's dolphins (*Grampus griseus*), and humpback whales (M*egaptera novaeangliae*) (IWC 2019). There is no government-managed bycatch management program, although a national prohibition on capturing cetaceans exists. Recently, WWF has conducted monitoring and mitigation studies that have created a wealth of information (e.g. Moazzam, 2019; Moazzam and Khan 2018; Kiszka et al., 2021, in revision).

Conservation Technology for Fisheries Monitoring

Conservation technology and applications to fisheries and megafauna are a nascent but rapidly growing field (e.g. Toonen and Bush 2020; Höschle et al., 2021). Satellite imagery is increasingly being used to provide information about cryptic marine mammal species, including habitat use, density and abundance, and their overlap with human activities (e.g. Fretwell et al., 2014; Leaper and Fretwall 2016; Cubaynes et al. 2019). At the same time, satellite imagery is also being used to describe the spatial distribution of fishing effort, especially for those without Automatic Identification Systems (AIS) or vessels engaging in illegal fishing (e.g. Al-Abdulrazzak & Pauly 2014; Rowlands et al. 2019, Park et al., 2020).

We propose to leverage applications of this emerging technology to provide more information in the data-poor case study of cetacean bycatch in the Indian Ocean. Specifically, we will use very high resolution (VHR) satellite imagery to characterize tuna drift gillnet fleets in Pakistan. VMS and AIS placed on industrial vessels allow ready tracking of industrial fleets, but this application is not widely available on semi-industrial vessels. Recent studies have used related methods in other regions (e.g. Exeter et al., 2021), but this will be the first known application of this technology focused on semi-industrial tuna drift gillnet fisheries and small cetacean bycatch in Pakistan.

Overview of Pilot Study

We selected Pakistan as our pilot case study because it is an important drift gillnet fishing nation, and also because its fisheries and bycatch are some of the best studied in this data-poor region. Ongoing, dedicated efforts by WWF-Pakistan to reduce cetacean bycatch in their drift gillnet fisheries, test mitigation measures, and establish crew-based observer programs have provided a strong baseline understanding of bycatch and the gillnet fishery in Pakistan and support policy making (Moazzam, 2019, Moazzam and Khan 2018). Furthermore, WWF-Pakistan holds extensive data on crew-derived bycatch estimates that have not been fully analysed, and national fisheries management organizations (mainly Provincial and Federal Fisheries Departments) have started requiring VMS on some vessels – creating opportunities for data analysis in an otherwise data-poor region.

Specifically, we propose to focus on the major fishing Ports of Karachi and Gwadar, Pakistan as our pilot study site and predominant source of satellite imagery collection. These are

the major ports for tuna drift gillnet vessels in Pakistan (Figures 2, 3, 4). We will also obtain images of vessels on fishing grounds, using information from Kiszka et al. (2021, in revision).[1] Using satellite imagery, we will count, measure, and classify tuna drift gillnet vessels. We will use this information to estimate how many drift gillnet vessels are present in this port and generate a rough estimate of total by-catch by analysing crew-based catch and bycatch data in these fisheries. Personnel from WWF-Pakistan will ground truth the number of vessels in Karachi and Gwadar, while also conducting a sample of fishermen interviews. This project leverages existing work done by WWF-Pakistan, collaborations with the IOTC, and data access to Worldview-3 satellite imagery through an agreement with Duke University. Our proposed project will act as a pilot study to test a novel approach to addressing small cetacean bycatch in tuna drift gillnet fisheries and will be designed intentionally to be scalable to other regions and fleets. We hope this work will help support Bycatch Mitigation Initiative priorities for work in the Indian Ocean region as discussed at the IOTC/IWC joint 2020 meeting (IOTC-IWC 2020), including: (1) "4.4.1 Collate all data available on bycatch of key species interacting with all tuna fisheries in the IOTC area (tuna drift gillnets, longlines, purse seines)," and (2) "4.4.2 Collaborate with other organisations […] and collect data on marine mammal bycatch interactions with gillnets across the IOTC region."

Figure 2. Image of drift gillnet vessels in the Port of Karachi. (Photo: WWF-Pakistan)

[1] Note: We would like to obtain satellite imagery for the entire study region represented by Kiszka et al., 2021 (in revision), but will likely be limited by budget constraints. We will obtain images as far into the Pakistani EEZ as our budget allows.

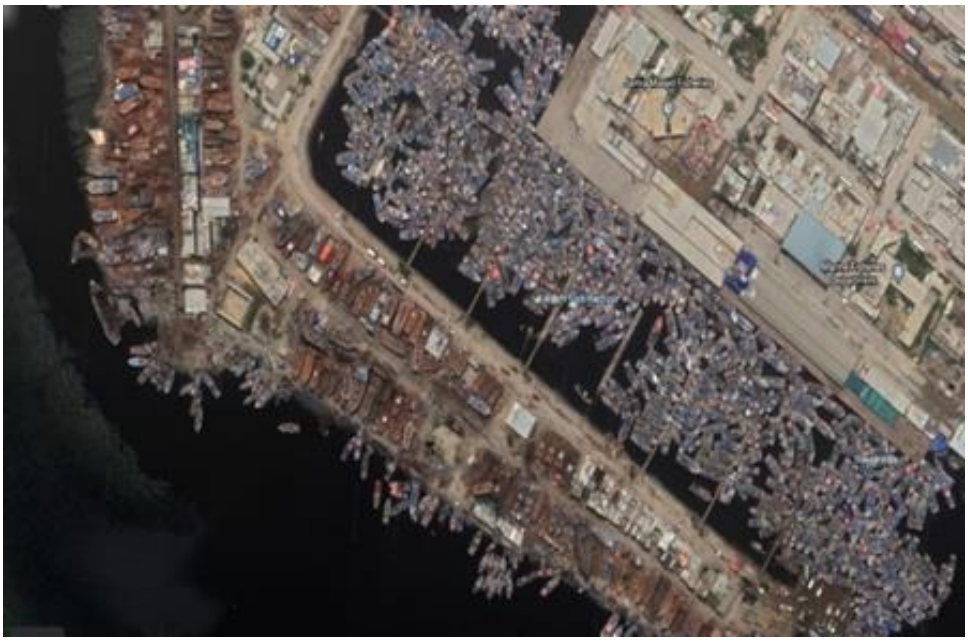

Figure 3. Google Earth imagery of fishing vessels in the Port of Karachi, March 2021. Maxar Technologies.

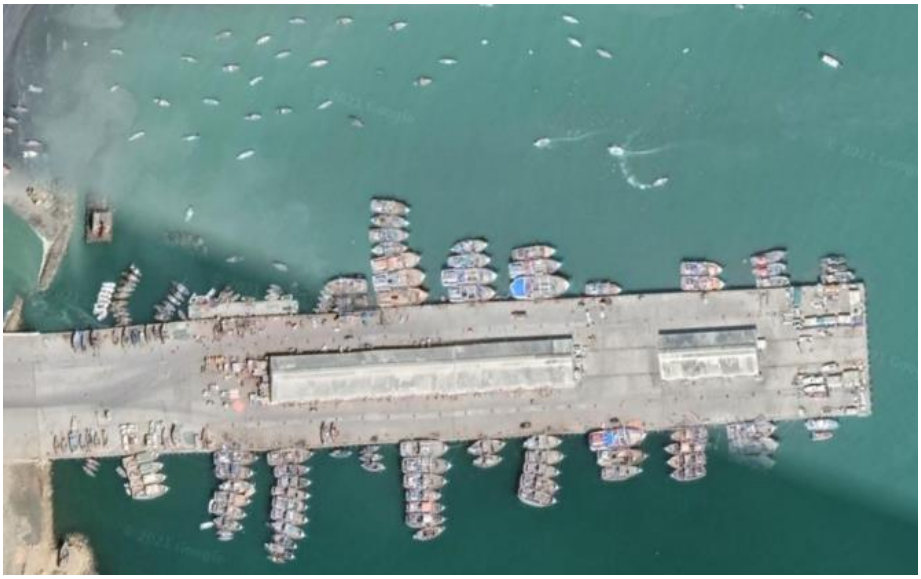

Figure 4. Google Earth imagery of fishing vessels in the Port of Gwadar, April 2021. Maxar Technologies.

Project Objectives

Our objectives fall into two areas: 1) testing and developing a novel interdisciplinary approach to understanding bycatch, and 2) better characterizing and quantifying tuna drift gillnet fleets in the Indian Ocean. Our specific objectives are as follows:

1. Use VHR satellite imagery and other earth observation data, coupled with ground-truthing and machine learning, to quantify and characterize tuna drift gillnet fishing vessels in port;
2. Assess the feasibility of using VHR satellite imagery and other earth observation data to capture images of tuna drift gillnet vessels on coastal and pelagic fishing grounds;
3. Leverage satellite imagery to estimate cetacean bycatch for tuna drift gillnet fleets;
4. Develop a transparent and transferable mixed-methods approach to obtain bycatch estimates in data-poor fisheries.

Author comments:

We acknowledge that we are in the early stages of this work. Our initial discussions have focused on identifying pilot study sites, identifying collaborators, and outlining our general work-plan; the next phase of this research will include fine-tuning our specific research questions we hope to address with satellite imagery; identify repositories for data storage; and identify analysis steps for image comparison, analysis, and machine learning. We seek feedback on the methodology, scope, and feasibility of this project as we move forward with planning.

Proposed Methods

This proposed project will occur in two phases:

1) Desk-based analysis of satellite imagery, machine learning, and bycatch estimates: The first step will be to assess imagery archives from the two proposed satellite sources, Maxar's GeoEye and Worldview 2 and 3 and the Planet "Dove" constellation, of the Ports of Karachi and Gwadar, and in the fishing grounds identified by Kiszka et al. (2021, in revision). Planet Labs provides images with a resolution of up to 3 meter per pixel and Worldview-3 offers the highest commercially available resolution at 0.31 m per pixel (Höschle et al., 2021). Duke University currently has access to Planet Labs images, and can also obtain imagery from Maxar for their Worldview and GeoEye platforms. We plan to use VHR imagery from both sources and compare their accuracy and utility.

Initially, we will retrieve archival images of the Port to 1) assess vessel and gear detectability and 2) train machine learning systems to detect and categorize vessels. We will also use archival images to account for any filtering needs. We will then request collection of new VHR scenes images for the proposed port study site at least monthly during the proposed project period. We will use images from August to May, as this avoids the summer monsoon season when fishing effort is minimal and satellite imagery will be obscured. We intend to run the project for at least one year, starting in May 2022. We will spend the monsoon season testing and training archival images, and then obtain new imagery starting in August.

Once images are acquired, we will manually assess images to detect and count gillnet vessels, using information collected *it situ* to guide analysts. These verified detections will then be used to train a convolutional neural network (e.g. ResNet variant implemented in Keras Tensorflow 2.0 or Pytorch) to identify and localize tuna drift gillnet vessels, count these vessels, measure vessel length, and, if possible, determine the presence of absence of drift gillnet gear on board. These data will be aggregated to create rasters of vessel counts to map this information.

Data will be processed and training using standard ENVI deep learning tools, and then mapped and analysed in R and ArcGIS.

A parallel workstream is to improve our understanding of the magnitude of small cetacean bycatch estimates for Pakistan. Several studies have attempted to generate bycatch estimates in Pakistan (e.g. Moazzam, 2019. Nawaz & Moazzam 2014, Shahid et al. 2016, Anderson et al., 2020), but this information is still quite limited. We will combine data generated from this project on vessel number, vessel size, and fishing patterns with crew-based observer data collected held by WWF-Pakistan, to explore ways to improve existing bycatch estimates. The exact methods for this calculation will be determined once the data are acquired and assessed.

2) Ground-truthing satellite imagery and outreach: On a monthly basis, WWF Pakistan will ground-truth information on the number of drift gillnet vessels in a standard area of parts of the Ports in Karachi and Gwadar. We will synchronize the ground-truthing work with collection of VHR satellite imagery. Additionally, WWF Pakistan will conduct a sample of interviews with captains about their fishing effort, catch, and bycatch and conduct outreach at the Port to explain the purpose of our study. We will work with WWF Pakistan to develop a standardized list of questions about catch, effort, and bycatch data. This ground-truthing process will allow us to assess the accuracy of the two types of satellite imagery and make recommendations as to which system to use in future work.

We expect the analysis to last for at least one year, commencing spring 2022-2023. Analysis and publication of results will occur in early 2023 and beyond the project.

Discussion

The confluence of data gaps and the current estimate of cetacean bycatch in tuna drift gillnet fisheries in the Indian Ocean make this a timely and urgent issue. IOTC management of drift gillnet fisheries is limited, and more data are necessary to inform management. This proposal leverages the expertise of researchers, the work of WWF-Pakistan, and the management role of IOTC. Our work is the start of a scalable methodology and has potential to significantly improve our understanding of bycatch in these fisheries, while aligning with priority of the Small Cetacean Sub-Committee, the BMI, and agreed recommendations by the IWC and IOTC.

We acknowledge multiple assumptions that underpin the success of this project. For example, we assume all vessels in Port are actively fishing; we may need to develop criteria to identify idle or derelict vessels. Our work assumes a relatively constant rate of fishing effort amongst vessels; we will address variation in fishing effort through interviews and ground-truthing. Finally, our ability to locate and identify drift gillnet vessels on pelagic fishing grounds and to cross-validate the identity of these vessels with satellite imagery from port surveys still needs to be verified.

We would like to pose several questions to the IWC SC HIM regarding our proposal. Given that we are in the early stages of this work, expert feedback on the methods, feasibility,

and any potential roadblocks will provide valuable insight. We are specifically seeking feedback on the following questions:

1. Are there other biases or assumptions we may be overlooking?
2. Are there other similar research projects with which we may want to collaborate?
3. Which other IOTC gillnet fleets should we focus on?

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