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Acoustic monitoring to document the spatial distribution and hotspots of blast fishing in Tanzania

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A B S T R A C T

Destructive fishing using explosives occurs in a number of countries worldwide, negatively impacting coral reefs and fisheries on which millions of people rely. Documenting, quantifying and combating the problem has proved problematic. In March–April 2015 231 h of acoustic data were collected over 2692 km of systematically laid transects along the entire coast of Tanzania. A total of 318 blasts were confirmed using a combination of manual and supervised semi-autonomous detection. Blasts were detected along the entire coastline, but almost 62% were within 80 km of Dar es Salaam, where blast frequency reached almost 10 blasts/h. This study is one of the first to use acoustic monitoring to provide a spatial assessment of the intensity of blast fishing. This can be a useful tool that can provide reliable data to define hotspots where the activity is concentrated and determine where enforcement should be focused for maximum impact.

1. Introduction

Coral reefs are of great economic, environmental and social importance to people, including some of the world's poorest communities (Donner and Potere, 2007; Cinner et al., 2013). Reefs are amongst the most biologically diverse and productive of the world's habitats, they are a valuable source of fish and other marine resources, defend shorelines against storms and erosion, and generate income from marine tourism, yet they are currently undergoing large-scale changes and degradation as a result of overfishing and climatic change (Bruno and Selig, 2007; Graham et al., 2008; McClanahan et al., 2015). More than 90% of coral reefs along the continental shores of the Indian Ocean are threatened by local or climate-related impacts, and more than one-third are believed to be at high or very high risk from local or global threats. This will have considerable negative consequences for communities and regions that rely on them for survival (Burke et al., 2011).

Fishing with explosives occurs in a number of countries in the world, particularly those in South East Asia, including Malaysia, the Philippines and Indonesia (Saila et al., 1993; Fox and Caldwell, 2006; Mazlan et al., 2005; Chan and Hodgson, 2017). Outside of southeast Asia, Tanzania is the only other country on the Indian Ocean where it is widely practiced (Burke et al., 2011). In Tanzania the activity began in the 1960s, has continued largely unabated since that time, and is considered to be more widely practiced now than at any other point in history (Slade and Kalangahe, 2015). Blast fishing has been described as an ecological calamity on par with elephant poaching and arguably worse as it results not only in the destruction of large numbers of organisms but also in complete obliteration of their habitat (Slade and Kalangahe, 2015). Coral reefs fringe the majority of the Tanzanian coastline, and they have become increasingly degraded from the widespread occurrence of blast fishing (Wells, 2009).

Bombs are home-made with kerosene and fertiliser, or explosives sourced illegally from the artisanal mining sector. Shallow areas and reefs that are known to have concentrations of fish are frequently targeted and stunned fish collected by hand or with nets. The underlying substrate, often coral, is usually shattered during the explosion and broken coral may then be extracted and used as building material. In addition to this, pelagic fish such as tuna are increasingly being targeted using surface blasts in deep water, and the fish then collected by scuba divers.

The damage caused by a blast can vary dramatically. This may depend on the types and sizes of charges used, the depths at which they explode, the depth of the water and the underlying substrate, all of which influence how the explosion propagates. Alcala and Gomez (1987) report that a bottle bomb (the most common size used in Tanzania) exploding at or near the bottom will shatter all corals within a

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radius of 1–2 m, and that a gallon-sized drum will have the same effect within a radius of 5 m. A 'typical' charge will kill most marine organisms including invertebrates within a radius of 10–30 m depending on the situation (Saila et al., 1993; Alcala and Gomez, 1987). Explosions kill fish by sending a shock wave through the water causing the internal organs, especially the swim bladder, to rupture and the skeleton to sustain thousands of fractures. It also kills plankton, juvenile fish, fish eggs, and invertebrates, the vast majority of which are never used. It is the destruction of hard coral and the overall reef structure which has the longest term detrimental effect on the environment. Reefs that are continually blasted have a marked reduction in fish and coral abundance and diversity. For example, in Tanga, fish densities were 12 times higher on a reef closed to fishing with little explosives damage as opposed to one nearby that was heavily impacted (Kaehler et al., 2008). While coral reefs can recover over 5–10 years from single blasts isolated in the reef matrix, extensive blast fishing such as that in Tanzania transforms these complex, biodiverse ecosystems into persistent expanses of shifting rubble. Because coral recruits are often unable to survive within these rubble fields, recovery can take several decades to centuries, even if reefs are protected from further blasting (Fox et al., 2005). The greater the extent of reef destruction the slower the period of recovery will be (Saila et al., 1993; Fox and Caldwell, 2006).

One of the driving causes sometimes attributed to the use of explosives to fish is local poverty, however, while this certainly plays a role, the individual fishermen often make less profit than the dealers and suppliers of explosives and related components, the boat owners and middlemen. Key enabling factors in Tanzania include, cheap and easy availability of explosives, well connected business men who market the fish and finance the activity, lack of local marine resource ownership or functional community fisheries management, ineffective law enforcement and lack of political will (Slade and Kalangahe, 2015). Putting an economic cost on the loss to society of destructive fishing is a useful way to justify the financial inputs of enforcement and other means of combating the issue. Blast fishing threatens the sustainability of Tanzania's fisheries, which were estimated in 2001 to contribute about 1.4% to GDP (Wilson and Wilson, 2015). It also has the potential to threaten the tourism industry which is of immense importance to the country's economy; in 2012 there were over 1 million visitors to Tanzania a large portion of which engaged in marine tourism, and tourism related income contributed 9.9% of GDP in 2013 (The World Bank, 2015). In Indonesia, the total cost of 'inaction' against blast fishing has been estimated at US$ 3.8 billion over the last 25 years; figures that would have justified enforcement expenditures of around US$ 400 million annually (Pet-Soede et al., 2000). It was also shown that the economic loss to society as a whole from blast fishing is at least four times higher than the net benefits to individuals from the activity (Pet-Soede et al., 1999).

Blast fishing in Tanzania is a long-term, widespread and pervasive problem, however, there have been very few studies that have documented its occurrence in space and/or over time. Tanzania is not unusual in this regard, similarly, there are very few quantitative reports of the distribution or intensity of blasting anywhere in the world (Woodman et al., 2004), although several countries are attempting to combat the problem. Information in Tanzania has been largely limited to anecdotal reports. For example, there were reported to be over 100 blasts on a single day on Mpovi Reef in Kilwa, 440 blasts were heard in Mnazi Bay, Mtwara in 2 months (7/day) and a maximum of 26 blasts in 3 h (8–9/h) (Guard and Masaiganah, 1997). Although these, and other such pieces of information from interested observers or fishers, provide an insight into the severity of the problem, and are useful for raising awareness of the need for action, a more systematic system of recording is required to fully understand the complexities of the issue throughout the country. Blast events have distinctive acoustic signals that can be detected underwater at an estimated range of 30 km or more (Woodman et al., 2003), therefore systematically monitoring blasts using underwater acoustic recorders is a good way to monitor occurrence in a manner that eliminates much of the subjectivity and error associated with human observations.

This study came about because in March and April 2015, a large-scale vessel-based survey to evaluate the whales and dolphins of Tanzania was conducted along the entire coast of the country (Braulik et al., in press). The survey used visual observations and acoustic recordings to locate and identify marine mammals. Inadvertently, in far greater numbers than identified cetaceans, the acoustic equipment also recorded underwater explosions from blast fishing. Analysis of these data has enabled us to present a first national assessment of the spatial intensity of blast fishing along the entire coast of Tanzania. The results clearly depict the vast scale of the problem, the wide geographical distribution of blasting activity and highlights important hotspots where environmental impacts are likely to be greatest and where enforcement should be focused for maximum impact.

2. Methods

2.1. Data collection

The survey was conducted for 36 days from March 1st to April 5th 2015 from a 50 ft. catamaran which sailed from Nungwi in Unguja (Zanzibar) to Mtwara (near the Mozambique border) and then proceeded to survey the entire coast of the Tanzania to the border with Kenya (Fig. 1). The boat motored at about 12 km/h along east-west transects. Each transect was approximately 50 km in length and was spaced 20 km apart, in a ladder type pattern. The boat anchored near shore each evening, and surveyed during daylight hours from approximately 07:00 h to 18:00 h. No acoustic recording was conducted at night. A Vanishing Point (http://vpmarine.co.uk/) stereo towed hydrophone array was deployed on 100 m of cable from the rear port-side of the boat throughout the survey when in water deeper than 20 m. The towing depth was between 5 and 10 m depending on vessel speed. The hydrophone array consisted of a Kevlar strengthened tow cable, a streamer section and a rope tail to reduce snaking of the hydrophone when towed. The streamer section contained two hydrophone pairs with different frequency ranges mounted in a 3.5 m long, 30 mm diameter, polyurethane tube. Only a high frequency hydrophone pair was used, which consisted of two Magrec HPO3 hydrophone elements spaced 0.3 m apart, each comprising a spherical hydrophone ceramic element coupled with a Magrec HPO2 preamplifier with 28 dB of gain and with a low cut filter set to provide − 3 dB at 2 kHz. The streamer section also contained a pressure sensor to provide information on tow depth and was filled with inert oil (Isopar M). Components were mounted on two 2.5 mm cords to provide strain relief and enclosed within plastic netting. A TASCAM DR-680 recorder was used to make continuous 2 channel, 192 kHz, 24 bit recordings. The files were saved without compression in .wav format, and were transferred to a backup hard drive at the end of each day.

2.2. Data analysis

The acoustic analysis was undertaken with the open source software programme PAMGuard (version 13.05) which allows for manual or automatic analysis of acoustic data, including acoustic detection, localisation and classification (Gillespie et al., 2008). The acoustic analysis was conducted primarily to detect and classify cetaceans, however, while manually examining the data, characteristic signals were identified, that on closer inspection of audio playbacks led to the conclusion that these detections were bomb blasts. The entire dataset was then examined manually and all potential blasts were marked. As described by Cagua et al. (2014) blast signals are transient signals with a sharp initial increase in amplitude. Most of the energy was contained within the first 0.2 s however this was often followed by a "tail" several seconds long. Blasts recorded at closer range were characterised by a strong onset and more energy in high frequencies (over 10 kHz) when