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

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ABSTRACT

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

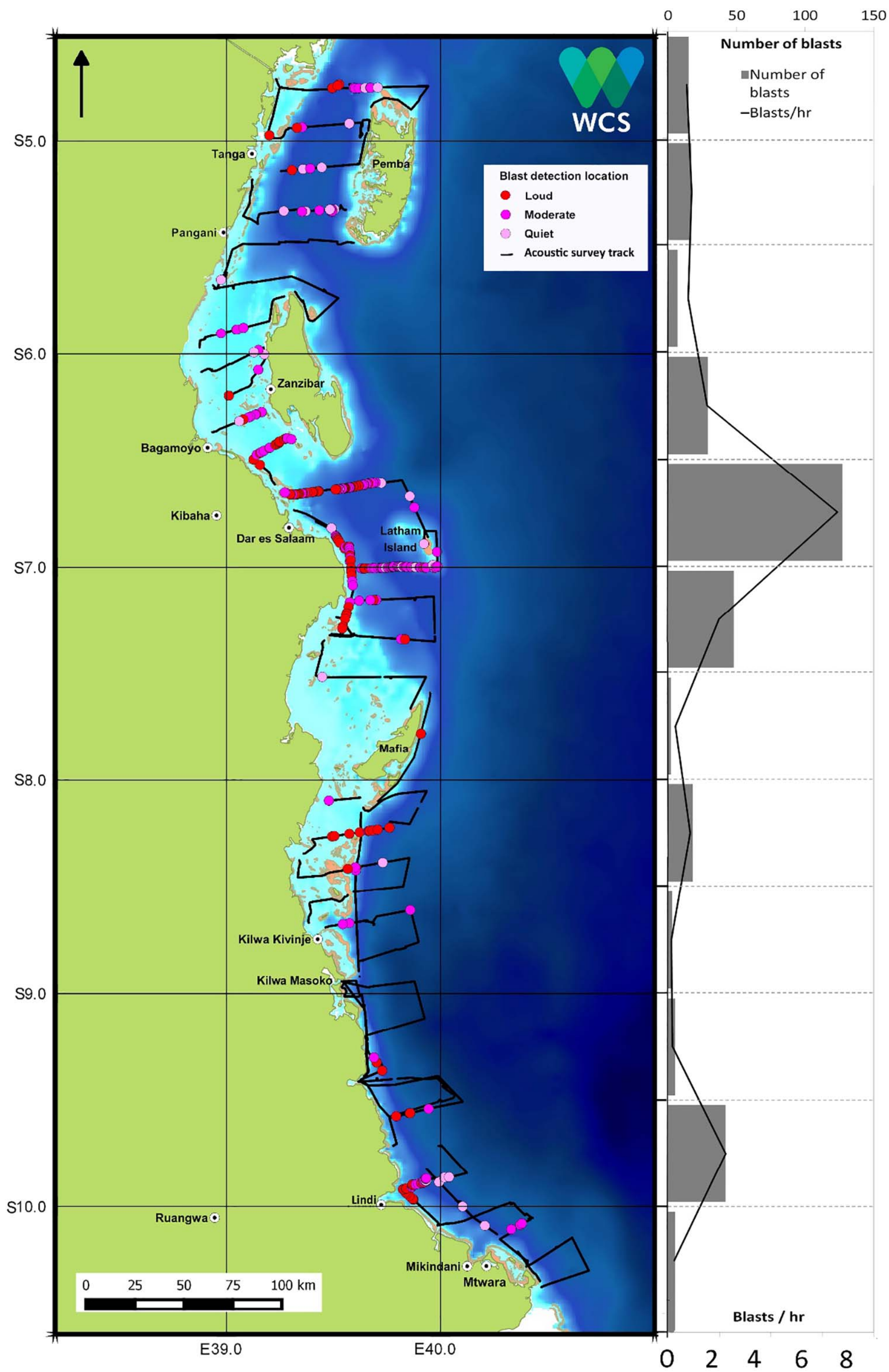

Fig. 1. Location of detected blasts and their relative amplitude along the entire coast of Tanzania in March–April 2014. (For interpretation of the references to colour in this figure, the reader is referred to the online version of this chapter.)

compared to distant blasts because seawater attenuates high frequencies at a faster rate than it does lower frequencies. Acoustic energy in distant blasts was largely below 5 kHz.

Based on these characteristics, we developed an automatic detector for putative blasts using a simple energy band detector available within PAMGuard (Gillespie et al., 2008). Parameter settings were adjusted to balance missed detections and false positives. Because the array was moving, background noise was variable, somewhat complicating the process of detection. Final settings for the detector included a minimum frequency of 500 Hz and maximum of 4000 Hz, peak threshold was 0.02, minimum time over the threshold 0.005 s and minimum time before the next detection 1 s. This frequency band and detector settings minimised false detections due to noise and biological sounds while maintaining detection efficiency. Echoes from loud blasts could also trigger the detector, therefore to ensure exclusion of echoes detected blasts that were within 1 s were merged. Any signals that were not detected on both hydrophones were excluded. This eliminated many false detections from knocks (e.g. fish, debris, algae etc.) that occur only on one hydrophone. Blasts that were detected using the automatic detector that were missed by the manual selection process were added to the master database along with their amplitude and bearing. A manual post-process check was conducted to remove obvious false positives such as snapping shrimp (*Alphaeidae*). Alpheid shrimp signals close to the hydrophone can have peak pressures larger than a distant blast. However, the shrimp pulse is of a much shorter duration than a blast, are of higher frequency (up to 20 kHz), and there are no echo's which make them easy to distinguish from genuine blast fishing signals (Woodman et al., 2003).

PAMGuard's MATLAB library was used to create a custom MATLAB script to extract time delays from detected bomb blasts. These data were then combined with information on the vessel's heading at the time allowing real world location information to be determined. Recordings with two hydrophones allow the location of a signal to be restricted to a 3D hyperbole of infinite length. In two dimensions (e.g. along the sea surface) this can be visualised as two possible bearings at equal angles to the left and right of the array orientation (left-right ambiguity). Therefore, two equally possible bearings along the sea surface were calculated for each blast: an array with three or more elements would be required to determine an unambiguous bearing. The peak to peak amplitude of each blast was calculated to provide an indication of the relative distance of the blast from the array. The acoustic system was not calibrated, but, as a general rule, blasts occurring closer to the hydrophone would be expected to have more energy at high frequencies than distant blasts, because energy at high frequencies attenuates more rapidly. Blasts of high amplitude are more likely to have originated closer to the hydrophone and those of low amplitude further away. However, while amplitude and spectrum can provide a rough indication of the relative distance of the blast from the hydrophone, it was not possible to calculate absolute distance. For analysis, blasts were categorized into three groups, Quiet, Moderate and Loud (Fig. 1).

3. Results

Acoustic data were collected for a total of 231 h over 2692 km of the Tanzanian coast on 31 days in March and early April 2015.

3.1. Acoustic blast detection

Results of the manual and automatic blast detection are shown in Table 1. The acoustic detector was only run on data from 3rd to 30th March because of slight damage to one of the hydrophone elements towards the end of the survey. Outside of this period blasts were processed only manually. The automatic detector detected 547 possible blast events that were recorded on both hydrophones, of these, 289 (53%) were false positives (i.e. snapping shrimp, knocks when taking array out of water, etc.) that were easily identified and removed after visual inspection. Of the remaining 281 blasts, 28 (about 10%) were new blasts that had not been identified manually. The automatic detector missed 23 events that had been identified manually (8% of the total). An additional 37 visual detections were made in the period not analysed by the detector (01/03–02/03 & after 30/03/3015). A total of 318 blasts were detected and confirmed using a combination of manual and supervised semi-autonomous detection. The relative received amplitude of detected blasts varied by 55.5 dB.

Table 1
Summary of blasts detected using manual and automatic detection methods.

	No. of blasts
03-March to 30-March	
Manual blast detections	253
Automatic blast detections	547
Number of automatic detections that were false positives	289
Number of manual detections missed by automatic selection	**23**
Number of confirmed automatic detections not detected manually	**28**
Number of blasts detected both manually and semi-autonomously	**230**
01 & 02 March and 31 March to 5th April	
Manual blast detections	**37**
Total confirmed blasts detected	**318**

Note: Adding together the figures in bold gives the total number of confirmed blasts.

3.2. Spatial distribution of blast fishing in Tanzania

The geographic location and amplitude of each of the 318 blasts detected during the survey are shown on Fig. 1. Blasts were detected along the entire length of the Tanzanian coast with virtually all areas affected. By far the highest intensity area for blasting was near Dar es Salaam. Most blasts were detected in the area stretching from Buyuni in Temeke in the South, to Mbweni just north of Kunduchi in the North. Some 123 blasts, 38.7% of all those detected, were within 50 km of Dar es Salaam, and 196 blasts, which is 61.6% of the total, were within 80 km of the city. The greatest number of blasts were detected on the 27th and 28th March 2015, during the transit from Temeke to Latham Island, and the return to Dar es Salaam, when 70 blasts (9.3 blasts/h) and 59 blasts (9.9 blasts/h) were recorded respectively. The graph in the right of Fig. 1 illustrates how the number of detected blasts varies with latitude along the length of the coast. Between 6.5 °S and 7 °S, the area around Dar es Salaam, an average of 6.6 blasts/h were recorded which is between 3 and 10 times more than at all other locations in the country.

A second smaller blasting hotspot was concentrated close to Lindi, where on 6th March 35 blasts (11% of the total) were recorded at a rate of 4.2 blasts/h. There was a concentration of blasts in the Tanga/Pemba Channel area where 32 (10% of the total) were recorded. A fourth small hotspot of blast fishing activity was around Songo Songo and Okuza Islands, South of Mafia. This is a location where blast fishing was also visually observed during the survey. No blasts were detected in the channel between Unguja and Pemba and only weak ones were detected west of Zanzibar so our survey, which gives a shap-shot at a single time, supports the general opinion that blast fishing is rare in these locations.

Blasts of high amplitude (red on Fig. 1 and 2) were generally detected nearer to shore, and those that were weaker (pink on the map) were generally further offshore indicating that the majority of the blast fishing activity is being conducted on reefs, and in shallow coastal areas rather than for pelagic species in deeper waters. Bearings to the origin of the blast were also calculated for each detection location and in most cases the bearing direction was towards the shore. However, some high amplitude blasts with bearings not directed to the shore were detected northeast of Dar es Salaam in the deep channel south of Unguja Island and in the Pemba Channel which suggests that some blast fishing to target pelagic species occurs in those locations. This is illustrated for the Pemba Channel where almost all detected blasts had a possible bearing towards Tanga (Fig. 2). The majority of blasting was recorded between the hours of 9:00 and 13:00 (Fig. 3).

Some blasts were detected in the waters of the semi-autonomous region of Unguja and Pemba Islands (Zanzibar), however they were mostly quiet with bearings towards Dar es Salaam or the mainland, and therefore were most likely to have originated outside Zanzibar waters. Similarly, blasts were detected all the way out to Latham Island, the majority were weak signals with bearings towards Temeke but according to the bearing data at least 11 may possibly have occurred around Latham island itself.

4. Discussion

4.1. Temporal and spatial distribution of blast fishing in Tanzania

This study is the first to provide a spatial assessment of the intensity of blast fishing along the entire coast of a single country; in this case the coast of Tanzania. The results clearly demonstrate the extent of this destructive fishing problem as almost the entire 800 km coastline of the

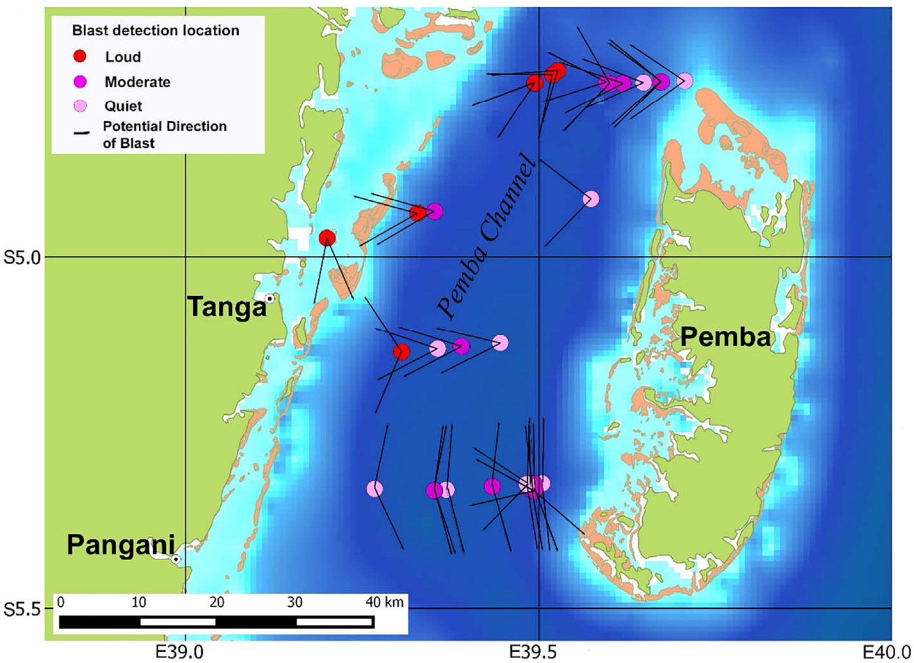

Fig. 2. Blasts detected in the Pemba Chanel between 2nd and 5th April 2015 along with relative amplitude and the two possible bearings to the blast origin.

country is affected. Blasting activity is largely centred close to urban areas (for example near Dar es Salaam and Lindi), presumably because of the ease of availability of explosives and other necessary components, sufficient man power and fuel, proximity to markets to sell the fish and demand from consumers. Similar to Horrill (1997) we recorded low levels of blast fishing activity south of Pangani to Bagamoyo, and also in portions of the southern coast, all of which are predominately rural areas.

Most blasting activity occurs during the morning, but blasts were recorded throughout the day, suggesting little evidence of concern for the risk detection by the authorities. We note a dip in activity that coincides with lunchtime and *Adhuhuri* Islamic prayers (Fig. 3). Both our study with data from the entire country, and that by Cagua et al. (2014) on a static acoustic recorder on Mbudya Patches, near Dar es Salaam showed that most blasting occurs during the morning, probably because the wind is generally lighter in the morning providing fishers with a better ability to locate schools of fish. The mean blast rate of approximately 19 blasts/day recorded by Cagua et al. (2014) is within the range recorded in the current study. The most intensive blasting activity was recorded near Temeke District, south of Dar es Salaam and in these locations we recorded 50–70 blasts/day (more than 6/h) making this the highest intensity area for blast fishing along the entire Tanzanian coast. Based on the results of this study we recommend anti-blast fishing operations and enforcement target Temeke as highest priority.

According to controlled studies by Woodman et al. (2003) small blasts can be detected at more than 12 km and possibly up to 50 km depending on the bathymetry and the mass of the charges being used. The blasts that we detected support this approximate distance of detection, for example if distant blasts were detected at around 30 to 50 km that would be consistent with the quiet blasts that were detected in the Zanzibar Channel originating near to Dar es Salaam, and those near Latham Island from Temeke. Similarly, in the Pemba Channel quieter blasts may have originated on the Tanga side of the channel approximately 30 km distant.

It is important to note that this study is a snapshot of blast fishing activity, there are almost certainly other geographic places in the country that are subject to blasting that were not identified because there was no activity on the day the survey vessel was present. Similarly, there are almost certainly seasonal patterns in blast fishing

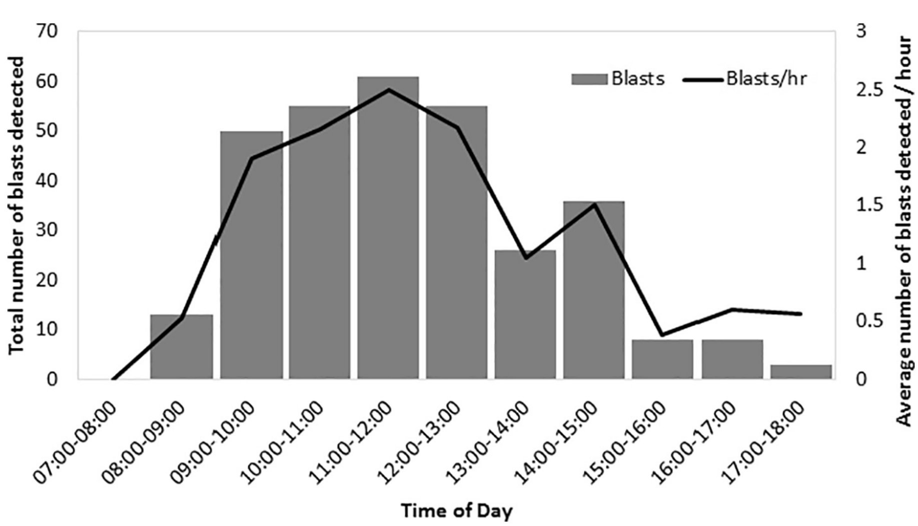

Fig. 3. Number of blasts and blasts/h according to time of day.

that may be linked to changes in weather and ocean currents, fish species present, market demand, and availability of explosives etc. High winds associated with a tropical cyclone were encountered when the survey was passing through Mtwara and Lindi, and as fishers seldom venture from land in bad weather, it is likely blast fishing activity is more prevalent in those areas than is suggested by our study. As depicted on Fig. 1, the array was not deployed in the Rufiji Delta, in the waters north of Mafia Island or close to the Tanga coast because of shallow waters, therefore an absence of blast detections in those areas does not mean that no blasting occurs there, these areas were simply not surveyed. Finally, to ensure the hydrophone was not damaged the survey vessel remained in water at least 20 m deep, and therefore in general did not enter very shallow coastal areas. It is therefore likely that very nearshore blasting or that conducted from the beach was not recorded because numerous islands and fringing reefs would likely dissipate the signal prior to detection. Given that much of the blasting appears to occur very close to shore, and because of the other factors noted above, the total scale of the blast fishing problem is almost certainly greater than suggested by this study.

4.2. Impacts of blast fishing on ecosystems and wildlife

There is substantial evidence that anthropogenic noise is detrimental to wildlife and ecosystems (Shannon et al., 2015). Many kinds of biological responses have been observed, ranging from individual behavioural changes to shifts in whole ecological communities (Shannon et al., 2015). Major concerns have been raised regarding the noise generated from shipping, industrial activities, seismic surveys and by the military in the world's oceans (Shannon et al., 2015). Here we have documented an additional acute and pervasive source of noise pollution that is occurring throughout the marine environment in Tanzania. The noise from blast fishing is likely to have effects on many sensitive species, especially as it is cumulative, on top of numerous existing anthropogenic noise sources.

Whales and dolphins use sound, or echolocation to navigate, search for food and communicate with each other and they are especially vulnerable to increases in underwater noise, which may disturb, displace, stress, injure or even kill individuals (McGregor et al., 2013). Explosions are especially dangerous because the intense shock wave causes sudden increases in cerebrospinal fluid pressure that may lead to brain damage, or they may present middle and inner ear damage, and also lung and intestinal haemorrhaging (Ketten, 1995). Less obvious than blast shock trauma but also serious is permanent threshold shift in hearing that may disrupt communication, breeding behaviour, or navigation (Santos et al., 2010). Given the scale of the blast fishing in Tanzania, the general sensitivity of cetaceans to anthropogenic sound, and the intensity of sound generated by explosions, it is almost certain that dolphins are impacted negatively by the activity. Of particular concern is the region's most endangered cetacean, the Indian Ocean humpback dolphin (*Sousa plumbea*) and the Indo-pacific bottlenose dolphin (*Tursiops aduncus*) both of which are restricted to shallow, nearshore waters which is exactly the habitat where blast fishing is most intense (Braulik et al., 2015). Similar detrimental impacts would be expected to other threatened marine megafauna such as sea turtles, dugong, whale sharks and many other species.

4.3. Acoustic detection of blasts

Automated detection of blasts from acoustic data collected from a moving platform in offshore waters may be easier than from moored recorders in shallow water, because of a more favourable, quieter acoustic environment with lower levels of snapping shrimp that interfere with automatic detection software. Monitoring from offshore waters also allows for the surveillance of larger swathes of the coastline. There is a great deal of variation in the acoustic characteristics of explosive blasts, as these are highly influenced by the environment and by propagation. Therefore, proximate and distant blasts have very different acoustic characteristics and this complicates development of an automatic acoustic detector that can identify the full range of signal types. In this case, we used a simple detector which generated a relatively high false positive rate (53%), and then used a human operator to distinguish and remove false detections. It was a relatively straight forward to examine all detections in PAMGuard and identify and exclude false detections, and we recommend using the detector in this type of supervised mode.

The bearing information proved to be very useful in determining approximately where the blast fishing was occurring, although in this case bearings could only be calculated with a left right ambiguity so positions were not precise. Future towed surveys could use 3 or 4 elements in two or three-dimensional arrays capable of providing unambiguous bearings. Other options that may be useful in distinguishing blast signals from noise would be to use widely spaced hydrophones several kilometres apart, or alternatively static or drifting sensors that incorporate clusters of hydrophones to provide bearing locations. Crossed bearings from widely separated clusters in conjunction with time of arrival differences in blast signals should provide actual locations for blast sources.

4.4. Applications of acoustic monitoring of blast fishing

The current study demonstrates the usefulness of acoustic monitoring in evaluating the incidence of blast fishing. While certainly not in itself the solution, the provision of improved information about the problem will clearly help support and direct those working to solve it. This information which identifies areas where blast fishing is most prevalent will assist with targeting enforcement and other operations to limit the availability of explosives and their components. Acoustic monitoring has a clear advantage in that it does not rely on networks of informers or human reporting which can be biased in numerous ways and it is standardised, quantified and repeatable. However, there can also be issues with costly devices being lost, stolen or malfunctioning that simpler human recorder systems would not face.

Deployment of a network of acoustic recorders along the Tanzanian coast could be used to systematically document baseline blasting levels in key locations. If deployed for an extended period, this would be able to prove quantifiable changes in the amount or pattern of blast fishing in response to specific enforcement operations and management interventions. This is an elegant way to reliably measure whether blast fishing is declining, and therefore demonstrate unequivocally the success of any anti-blast fishing activities. Repeating the current survey at regular intervals would demonstrate how geographic hotspots of blast fishing may be shifting over time and whether, for example, as it declines in one area following successful interventions, the activity then erupts elsewhere. Being able to monitor success is vital.

Theoretically blasts could be detected and located in near real-time, and information transmitted immediately to law enforcement officials allowing them to launch a response. There are however, challenges to this in terms of current technology, and it would likely be necessary to adapt existing systems that locate and identify whales and dolphins in real-time using hydrophones mounted on ocean gliders, or fixed monitors (Baumgartner et al., 2013; Barker and Lepper, 2013; Gillespie et al., 2008; Van Parijs et al., 2009). For real-time data transmission, a portion of the device must be above the sea surface therefore increasing the likelihood of vandalism, damage, theft or loss. Despite this, a form of real-time blast detection linked to law enforcement has been trialled in Sabah, Malaysia with success leading to some arrests (Wood and Ng, 2014). However, this technological solution will be expensive and is not a panacea, it will only be effective if it is possible to successfully arrest, prosecute and convict those responsible, and if there are sufficiently strong penalties to deter re-offense. At present these aspects are not in place in Tanzania (Mugeta, 2013), although there are measures in process to increase penalties and to raise awareness of the issue amongst the judiciary (Haule, 2013).

4.5. Combating blast fishing

Blast fishing in Tanzania is a complex issue that has proved extremely difficult to combat. The solution requires the sustained coordinated efforts of numerous different stake-holders at multiple levels across the country (Slade and Kalangahe, 2015). In addition to concerns about the environment, the wide availability of explosives along the coast is a concern for national or even regional security. As is often the case, those that are profiting the most in the short-term from this activity are not those that will suffer the greatest long-term consequences. The environmental degradation that results from large-scale blast fishing in lost tourism revenue, declining fish catches, reduced resilience of coastal communities and reefs to climate change and natural disasters, as well as many other indirect impacts are likely to amount to many millions of dollars of loss to the country. Strengthening the ability of communities to provide stewardship of local marine resources and to take a strong role in their management, coupled with effective and engaged law enforcement will be essential before this illegal and destructive activity can be stopped (Slade and Kalangahe, 2015).

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