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Cover image: The mudskipper *Periophthalmus argentilineatus* on the mangrove of Ulo Beach, Cabo Delgado, North Mozambique. © José Paula, 2006

Quick and cost-effective mapping of subsistence and artisanal fishing areas within and adjacent to a marine protected area

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Abstract

Spatial information on artisanal fisheries is largely lacking, making subsequent management and threat or impact assessments difficult. Local knowledge, current and readily available mapping software and Global Positioning System (GPS) techniques were used to map small-scale (subsistence and artisanal) fishing areas within and adjacent to the western boundary of the Ponta do Ouro Partial Marine Reserve in southern Mozambique. Data on habitat types were collected in the field and combined with available literature. Thirty-one fishing areas were identified and mapped resulting in a total area of 293.1 km² with a perimeter of 396.7 km, from the Inhaca Island lighthouse in the north to the Maputo River mouth in the south. Habitats within the fishing areas included isolated intertidal sand banks, seagrass beds, estuarine channels, as well as intertidal muddy areas adjacent to the coast. The fishing areas covered on average 9.5 km² (SD=12.0) and varied immensely in size (0.3–50.1 km²). Overall, 58.4 % (171.2 km²) of the total fishing area mapped was located inside the reserve. Costs associated with data collection equated to an average of U$D 3.61 per mapped km² or U$D 2.63 per km tracked. The method was found to be quick, cost-effective and easily replicable elsewhere.

Keywords: artisanal and subsistence fishing areas, local knowledge, Maputo Bay, Ponta do Ouro Partial Marine Reserve, small-scale fisheries, spatial mapping

Introduction

The small-scale (subsistence and artisanal) sub-sectors constitute the backbone of marine fisheries in most developing countries, especially in the Western Indian Ocean (WIO) region (van der Elst *et al.*, 2005; Groeneveld, 2015). In Mozambique, more than 315 000 people are directly involved in artisanal and subsistence fisheries (Ochiewo, 2015), with reported catches of 314 470 tonnes in 2017, whereas the combined catches reported for the industrial (15 100 tonnes) and semi-industrial (8 806 tonnes) sub-sectors represented less than 10 %, in the same year (MIMAIP, 2019).

Common challenges associated with the management of small-scale fisheries include lack of baseline data, limited/over-exploited resources, high numbers of fishers, weak governance and political will, poor or ineffective enforcement and management regulations, and open access rights (Béné *et al.*, 2004; Salas *et al.*, 2007; Batista *et al.*, 2014). Several authors have advocated that these challenges in conjunction with the socio-economic importance of small-scale fisheries for developing countries make user participation essential (Léopold *et al.*, 2014; Corral and de Lara, 2017). The application of local knowledge to support planning and management of artisanal fisheries has thus gained widespread acceptance and use (Hele, 2007; de Freitas and Tagliani, 2009; Ratsimbazafy *et al.*, 2016; Thiault *et al.*, 2017).

One of the simplest ways to acquire and make use of local knowledge is the mapping of fishing areas – a data collection method used to develop a participatory geographic information system (Dunn, 2007). Within the WIO, participatory mapping of fishing areas has been achieved in Madagascar for

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the octopus fishery (Ratsimbazafy *et al*., 2016), in Kenya for the ringnet fishery (Thoya *et al*., 2014) and main fishing grounds of migrant fishers (Wanyonyi *et al*., 2018). Hele (2007) and Book (2012) mapped hand-lining and gillnet fishing areas in northern and southern Mozambique, respectively. Primarily, these studies involved participatory drawing of habitat maps and fishing areas, which where later digitised into GoogleEarth maps and then validated by the fishers. While this technique is largely advocated as being cost effective, the accuracy is generally poor. Wanyonyi *et al*. (2018) presented an alternative, yet slightly more costly approach; eleven handheld GPS units were provided to fishers for tracking of fishing activities which were complemented with vessel logbook records.

This paper reports on a quick, easy and cost-effective participatory mapping method used to characterize fishing areas of artisanal and subsistence fishers within and adjacent to the Ponta do Ouro Partial Marine Reserve (POPMR) in southern Mozambique. Here, the two general approaches used in previous studies in the WIO are combined. The method entailed tracking the actual perimeters of the fishing areas, using a readily available GPS unit and open source mapping software followed by validation by the fishers. This constitutes the first baseline for spatial small-scale fisheries data for a marine protected area (MPA) in Mozambique.

Materials and methods

Study area

The POPMR is located in southern Mozambique and is administratively part of two coastal districts of Maputo Province – the Matutuíne District and the KaNyaka Municipal District (which in turn falls under the Maputo Municipality). The geographical limits of the POPMR are from the border with South Africa to the south, and Cabo da Inhaca to the north, to the Maputo river mouth in Maputo Bay (Fig. 1). The reserve covers 678 km^2 and stretches from the highwater mark, following the contour of the base of the coastal dunes, to three nautical miles into the Indian Ocean, and one nautical mile into Maputo Bay (DNAC, 2011).

The study was performed on the western side of the reserve (i.e. within Maputo Bay), from the Inhaca lighthouse to the Maputo river mouth, a stretch of coast of about 70 km. The general area is described in detail in Bandeira and Paula (2014). The area is very shallow, with the deepest points within channels attaining about 20 m. At low tide, the average depth ranges from the intertidal zone to about 10 m. The study area consists of a series of seagrass and muddy intertidal sand banks which are almost continuously fringed by mangroves. The area is subjected to multi-gear and multi-species fisheries, including beach and boat seining, gill netting, hand-lining, traps, spear-fishing, as well as invertebrate collection (Louro *et al*., 2017).

Data collection and analysis

The data were collected over four working days (total of 27 h and 20 min) between June and July 2017. The area was divided into three main strata following the reserve's subsistence and artisanal catch monitoring system, namely: Inhaca Island, Santa Maria, and Mabuluco (Louro *et al*., 2017). For each stratum, a Google Earth map of the area was printed on A3 paper and discussed with experienced fishers (n=3) familiar with the area, usually the leader of the local community fishing council. The names of the fishing areas were previously obtained from the artisanal catch monitoring system and the approximate boundaries of each area were identified and confirmed by the fisher.

A shallow draft, 19-foot catamaran ski-boat, powered by twin 90 HP four-stroke motors was used to travel within the perimeter of each area. The local fishers joined the surveying team on board to validate the areas that were mapped. The boat was equipped with a Garmin GPS/fish-finder combo (Garmin echoMap CHIRP 94SV), which tracked the perimeters of the areas. Notes on the general characteristics of the area, including the bathymetry and bottom type were collected. Bottom type was determined by using a combination of information from the fish-finder on board, the local knowledge of the fisher and a GoPro camera, lowered to the bottom with weights and set in a time-lapse photo mode. These data were then combined with information from available literature (Kalk, 1995; Bandeira *et al*., 2014; Ferreira and Bandeira, 2014).

The tracks of each day's work were transferred to Garmin's free mapping software (Homeport 2.2.10) from which the coordinates of the perimeters were extracted and transferred into GoogleEarth to snap vertices and edges of the polygons. Preliminary maps were produced using QGIS 2.18, and then discussed with the fishers for amendments and validation. The shapefiles of the Mozambican coastline, Maputo Bay and the POPMR were downloaded from free online sources (Biofund, 2019; Flanders Marine Institute, 2020).

Results and discussion

Thirty-one fishing areas were identified and mapped (Fig. 1, Appendix 1), representing a total surface area of 293.1 km² and a perimeter of 396.7 km. The fishing areas included isolated intertidal sand banks, seagrass beds, sandy/muddy areas, estuarine channels, as well as intertidal muddy areas adjacent to the coast. The fishing areas covered on average 9.5 km² (SD=12.0) and varied greatly in size (0.3–50.1 km²). A few areas (n=6; totalling 47.3 km², 16.4 %) were located outside the limits of the POPMR, whilst the majority were located inside the reserve (n=15), although relatively small and thus representing only 19.4 % of the total surface of the fishing areas mapped (56.8 km²). Some large fishing areas (n=10) overlapped the reserve's boundaries, representing 64.5 % (189 km²). Overall, 58.4 % (171.2 km²) of the total fishing area mapped was located inside the reserve.

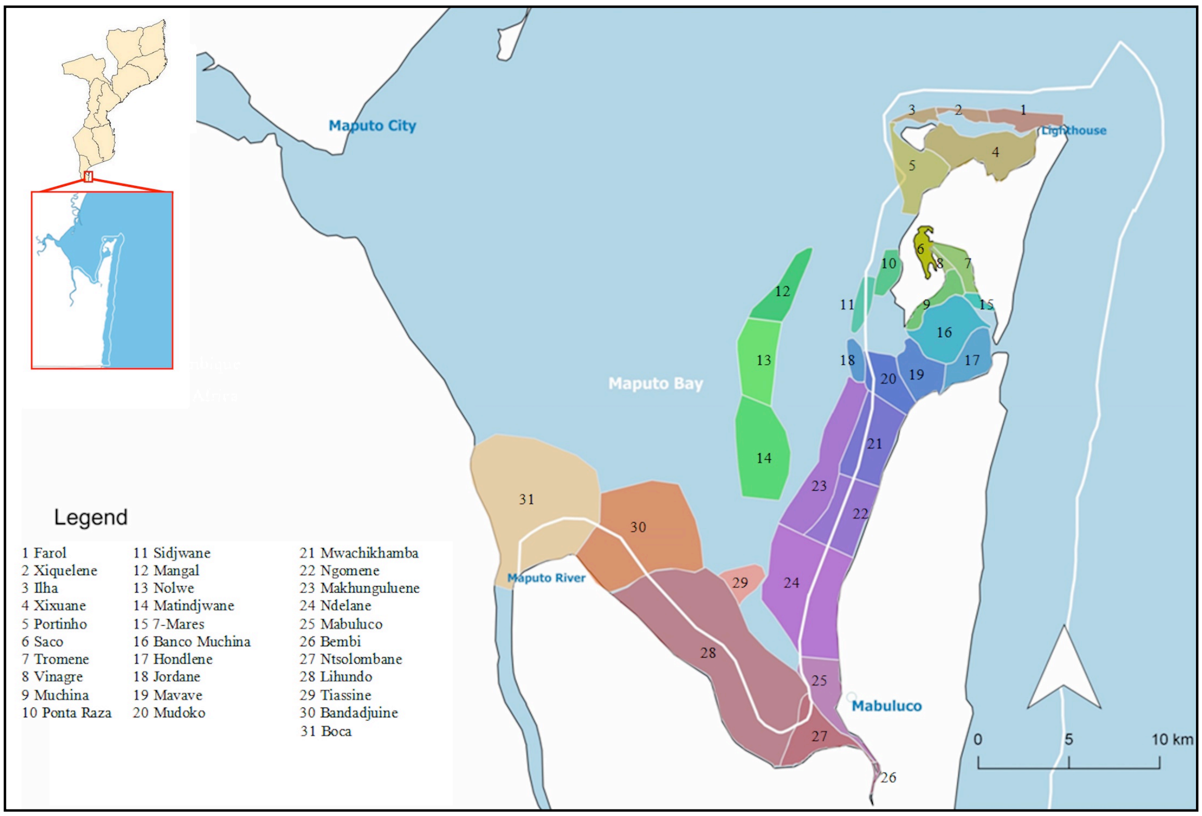

Figure 1. Map showing the location of the Ponta do Ouro Partial Marine Reserve (inset) and the subsistence and artisanal fishing areas (n = 31) mapped in this study. White perimeter defines the POPMR boundary area.

Some previous mapping of this study area has been conducted but the results from the present study differ in relation to accuracy and the total area covered. The most probable explanations for these differences are as follows. The study by Book (2012) reported 23 fishing areas used by fishers from Inhaca Island, of which 47 % were located inside the reserve, 28 % outside the reserve's boundaries and the remaining 25 areas were trans-boundary. These discrepancies probably result from the fact that the present study covered a larger area inside the Bay and was not restricted to the area surrounding Inhaca Island or only used by fishers from the island. Book (2012) mentioned fishing grounds in the open ocean (e.g. Baixo Danae), which were not covered by the present study. Additionally, Book (2012) did not quantify areas or perimeters of the fishing areas, which constitutes a significant shortcoming and makes any comparison difficult. Also, the study was based solely on identification of areas used by the fishers from a printed map, so the accuracy is indeed questionable (due to the fishers' difficulty in interpreting and scaling maps).

Only three fishers were interviewed and participated in the present study. Notwithstanding their local knowledge and experience (all three are affiliated with local fishing councils), it is recognized that the accuracy of the limits and location of the fishing areas could definitely be improved with more participants. This would be of value in areas where conflicts may exist amongst fishers, and the participation of a larger number of fishers to verify and validate the maps produced both in a workshop and *in situ*, would certainly contribute to strengthen the relationship between fishers, managers and researchers as reported by Ratsimbazafy *et al*. (2016).

The overall costs associated with data collection in the field (including fuel, boat use, *per diems* and fishers' time) totalled about U$D 1 045.00, which equates to an average of U$D 3.61 per km^2 of mapped area or U$D 2.63 U$D per km tracked. Unfortunately, there are no estimates of the costs involved in mapping fishing areas from previously published works in the WIO (cf. Hele, 2007; Book, 2012; Thoya *et al*., 2014; Ratsimbazafy *et al*., 2016; Wanyonyi *et al*., 2018), which makes any comparison difficult, if not impossible. However, taking into account that for a given MPA or locally managed marine area this would be a one-off cost, and given how quickly the information is generated with substantial accuracy, the method is considered to be very cost-effective.

This mapping method could prove useful in environmental impact assessments, marine spatial planning initiatives, endangered species or ecosystems conservation, and the participatory drafting and implementation of conservation and fisheries management plans. In fact, the map of fishing areas generated has been shared with the reserve's authorities and relevant stakeholders and is being used in the planning, monitoring and management of coastal resource use within the reserve (Williams *et al*., 2018). It is worth mentioning the need for ground truthing and collecting data *in situ* when conducting similar mapping exercises, which results in more accurate, quantitative mapping data. In conclusion, the method is simple, quick and cost-effective and, given the readily available techniques and resources used, it can be easily replicated in developing countries.

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Appendix

Table A1. Summary description of artisanal and subsistence fishing areas mapped, within and adjacent of the Ponta do Ouro Partial Marine Reserve. Ecological Information was collected during the present study and compiled from the literature (Kalk, 1995; Bandeira *et al.*, 2014; Ferreira & Bandeira, 2014).

Nr.	Strata	Fishing Area	Perimeter (km)	Surface (km^2)	General description
1	Inhaca	Farol	11.3	3.6	Sandy substrate. Channel with an intertidal area interspersed with sand banks influenced directly by the Indian Ocean. The shore encompasses sandy beaches and high vegetated dunes
2	Inhaca	Xiquelene	7.2	1.4	These areas are essentially a continuous channel with sandy substrate. The shoreline encompasses a continuous and slightly elevated sandy bar with pioneer dune vegetation
3	Inhaca	Ilha	6.7	1.3	
4	Inhaca	Xixuane	18.5	11.3	Intertidal sandy to muddy substrate covered by two main seagrass communities: *Thalassia hemprichii* and *Halodule uninervis*. Between Portuguese Island and Portinho, at Inhaca Island, there's a seagrass community of *Thalassodendron ciliatum* and *Cymodacea serrulata*. At low tide most of the area is exposed. On land, the Sangala Bay non-estuarine mangrove forests are still in good condition
5	Inhaca	Portinho	14.4	8	The area is mostly submerged and shares the same seagrass community (*T. ciliatum* and *C. serrulata*) with Xixuane. The shoreline is mainly composed of red sand cliffs (Barreira Vermelha) and sandy beaches with coral rubble
6	Inhaca	Saco	9.5	1.9	Intertidal sandy to muddy substrate covered by three main seagrass communities: *T. ciliatum* /*C. serrulata*, *T. hemprichii*/*H. uninervis* and small patches of *Zostera capensis*. Adjacent to the seagrass beds, there are non-estuarine mangrove forests composed mostly by fringing *Avicenna marina* and *Rizophora mucronata* (mostly on creeks)
7	Inhaca	Tromene	4.4	0.6	Sandy to muddy substrate covered by four seagrass species (*T. ciliatum*, *C. serrulata*, *T. hemprichii* and *H. uninervis*)
8	Inhaca	Vinagre	8.6	2.8	
9	Inhaca	Muchina	10.7	3.1	Thsomene channel (sandy/muddy substrate) bordered by intertidal sand and muddy banks with seagrass communities (*T. ciliatum* /*C. serrulata*, *T. hemprichii*/ *H. uninervis* and small patches of *Z. capensis*). The shoreline is fringed by *A. marina* and *R. mucronata* (mostly on creeks)
10	Inhaca	Ponta Raza	6.9	2.6	Intertidal mostly sandy substrate, with two main seagrass communities (*T. ciliatum* and *C. serrulata*). The shoreline encompasses sandy beaches and pioneer dune vegetation

Nr.	Strata	Fishing Area	Perimeter (km)	Surface (km^2)	General description
11	Inhaca	Sidjwane	7.5	2.6	An isolated and intertidal sand bank bordered by a channel and covered by non-continuous seagrass bed communities of *T. ciliatum* and *C. serrulada*. The shoreline encompasses sandy beaches, rocky outcrops and pioneer dune vegetation
12	Santa Maria	Mangal	11.9	5.5	Sandy substrate with *T. ciliatum* and algae. An isolated intertidal bank bordered by a deep channel and covered by non-continuous seagrass bed communities
13	Santa Maria	Nolwe	12.7	9	Sandy substrate with *T. ciliatum* and algae. An isolated and intertidal sand bank bordered by a channel and covered by scattered seagrasses
14	Santa Maria	Matindjwane	15	14	Sandy substrate with *T. ciliatum* and algae. An isolated and intertidal sand bank bordered by a channel and covered by non-continuous seagrass beds
15	Inhaca	7-Mares	4.5	0.9	Sandy to muddy substrate covered by three seagrass species (*T. hemprichii*, *H. uninervis* and *C. rotundata)*
16	Inhaca	Banco Muchina	13.3	9.4	A large intertidal sand and muddy bank covered mainly by a large patch of *Z. capensis* and smaller patches of seagrass communities of *T. ciliatum / C. serrulata*, *T. hemprichii / H. uninervis*. The bank is bordered by the deep Thsomene channel
17	Santa Maria	Hondlene	10.7	5.2	Sandy substrate with a seagrass bed composed mainly by *T. ciliatum.* The sand bank is borderd by the Sisse channel. The shoreline is fringed by mangroves (*A. marina*). Vegetated coastal dunes, sandy beaches with rocky outcrops also characterize the shoreline
18	Santa Maria	Jordane	5.9	1.9	Isolated, intertidal sandy bank with seagrass beds composed mainly by *T. ciliatum, C. serrulata* and macroalgae. Borderd by a shallow channel
19	Santa Maria	Mavave	10.3	5.7	Sandy substrate with seagrass bed composed mainly by *T. ciliatum* and bordered by the Xihogo channel. The shoreline is fringed by mangroves, mainly *A. marina*
20	Santa Maria	Mudoko	10.3	5.8	Sandy substrate with macroalgae and deposits of broken mollusc shells. Fringed by *A. marina* on the seaward margins and *R. mucronata* along the creeks. Extensive muddy intertidal area, adjacent to the mangroves
21	Santa Maria	Mwachikhamba	14	10.8	Sandy and mostly muddy substrate. Fringed by mangroves, mostly *A. marina* and *R. mucronata* along the creeks. Extensive muddy intertidal area, adjacent to the mangroves
22	Santa Maria	Ngomene	13.6	9.7	

Nr.	Strata	Fishing Area	Perimeter (km)	Surface (km^2)	General description
23	Santa Maria	Makhunguluene	21	13.7	Sandy substrate with rocky and seagrass patches composed mainly by *T. ciliatum* and algae. Gradient between the estuarine ecosystem and the channel. Composed of an array of small intertwined channels and sand banks
24	Mabuluco	Ndelane	20.7	24.5	Sandy and mostly muddy substrate. Fringed by *A. marina* on the seaward margins and *R. mucronata* along the creeks. Extensive muddy intertidal area, adjacent to the mangroves
25	Mabuluco	Mabuluco	16.5	6.7	Adjacent to the mouth of the Bembi esturary. Muddy/sandy substrate with a scattered algae covered banks and deposits of broken mollusc shells. The shoreline encompasses red sand dunes, with sparse mangrove trees and rocky outcrops. Fish traps commonly known as "gamboas" were commonly observed
26	Mabuluco	Bembi	5.5	0.3	At the mouth of the Bembi estuary. Muddy substrate. High turbidity. Fringed by mangroves, mostly *A. marina* and *R. mucronata*. On the eastern bank (Mabuluco side), there were signs of mangrove clearance. On the western bank, vigorous natural mangrove regeneration is taking place. Along the fringing mangrove forest, several creeks are used as pathways and anchoring sites
27	Mabuluco	Ntsolombane	16.4	7.1	Sandy to muddy substrate with scattered deposits of broken mollusc shells. Fringed by *A. marina* on the seaward margins and *R. mucronata* along the creeks. Extensive muddy intertidal area, adjacent to the mangroves. Obvious natural mortality of mangroves (tall dead trees). Fencing nets (gamboas) were commonly observed in this area
28	Mabuluco	Lihundo	33.6	50.1	Muddy substrate. The shoreline is fringed by *A. marina* on the seaward margins and *R. mucronata* along the creeks. Extensive muddy intertidal area, adjacent to the mangroves. Fencing nets (gamboas) were commonly observed in this area
29	Mabuluco	Tiassine	7.5	3.2	Deep channel with muddy substrate. Important hand-lining area
30	Mabuluco	Bandadjwine	21.6	29.4	At the mouth of the Maputo river. Muddy substrate with intertidal muddy/sandy banks with extensive deposits of broken mollusc shells. Very turbid water. Estuarine ecosystem fringed by *A. marina* on the banks and *R. mucronata* along the creeks. Fishing traps (gamboas) were commonly observed in these areas
31	Mabuluco	Boca	26	41	