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Disentangling the net:

The socio-ecological dynamics of mosquito net fishing

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A thesis submitted for the degree of Doctor of Philosophy

Imperial College London

September 2018

Abstract

The use of mosquito nets, largely handed out for free in efforts to control malaria, as fishing gear is anecdotally widespread. Mosquito net fishing (MNF) is condemned as a threat to food security and biodiversity due to its assumed but unsubstantiated 'indiscriminate' nature. A number of countries have banned the activity though no empirical investigation of the impacts or drivers of MNF exists. In this study I conduct a holistic investigation in to MNF, using a socio-ecological systems approach to characterise MNF, assessing its relevance to Sustainable Development Goals.

I first review relevant assumptions of negative social and ecological impacts of MNF; discussing potential for positive impacts in terms of food and nutrition security, livelihoods and social equity. I present a conceptual framework which is then utilised to direct policy analysis across relevant sectors in a workshop setting through expert knowledge elicitation. Potential strategies to address MNF across health, development and fisheries governance structures are presented. I also conduct the first global assessment of the prevalence and characteristics of MNF, highlighting its widespread nature.

Using a case study in Cabo Delgado, Mozambique I test both entrenched and emerging the ories on the drivers and impacts of MNF in a coral reef fishery. Using a rapid assessment of fish landings I demonstrate the likely impact of MNF on catches of legal gears and biodiversity. MNF is a gendered activity, whereby predominantly androcentric methods show potential for negative impacts but gynocentric methods show limited resource overlap. I then use a household survey to contextualise the food security and livelihoods contributions of MNF. MNF is shown to be an important part of household livelihood profiles and particularly in adaptive strategies beyond subsistence in mixed agriculture and fishing communities.

The research legitimises concern over MNF sustainability but highlights recklessness in current management based on broad, unsubstantiated assumptions; particularly ineffective enforcement policies. I demonstrate opportunities for MNF to enhance wellbeing and discuss this in light of relevant paradigm shifts, highlighting the critical need for further investigation.

Declarations

This thesis results entirely from my own work. The work of all others is appropriately acknowledged and referenced in the text.

Rebecca Short, September 2018

Copyright Declaration

Acknowledgments

I never thought I would believe in a higher power until I embarked on the journey that has produced this thesis – but I see no feasible explanation other than there is someone up there messing with me. However, in Her unfathomable wisdom I have been blessed with the most incredible support I could have hoped for. Thanks first to my supervisors: E.J. Milner-Gulland for being an unflappable and wholly understanding influence, even when I decided to move several hundred miles away; Nick Hill for a reassuring open door policy which he will probably long regret; and Marcus Rowcliffe for tactfully bringing things back down to earth when all too necessary.

I have had the great privilege of spending time with numerous academic communities during my PhD and they have been universally wonderful to be a part of. To my ZSL colleagues thank you for kicking me off (or out?) Dave Curnick, I'm pretty sure this was all your fault but you made up for it with your calming dengue diagnoses over WhatsApp, and all the pints. Mike Hudson, cheers for being an excellent first office buddy, especially the mid-afternoon dumping of a bottle of wine on my desk during a particularly hairy period. For navigating the halls and pubs of Oxford with me, an always welcoming sofa and a partner in jam-related crimes, thank you to ICCS and my fellow intrepid explorers; Beccy Wilebore, Emilie Beauchamp, Sam Earle and Tom Hart. To everyone at Exeter for being so welcoming when I turned up unannounced and then never left; thank you for making Cornwall the perfect antidote. A big shout out to George Swan for a mixture of supportive and dependent house-matery, and Katie Shanks for pretty much never letting me say no to anything, especially if it's scary and high.

*Huge thanks to the ZSL and AMA Mozambique teams for their support during various bouts of panic, also to Anouk Neuhaus without whom Mozambique would have been much harder. Jamen Mussa, I do not know where I would be without you. I certainly wouldn't have any data, but more than that the 257 games of s**thead on the beach were critical to sanity – I still can't believe you beat me by 5 games; the student truly did become the master. Also, massive thanks to the rest of my data collection team: Veronica Tome, Vasco Lino, Juvencia Manda, Mamudo Abudo, Isildo Nganhane. To the wonderful and welcoming people of the villages of Malinde and Quirinde; thank you, I hope for your safety every day.*

Thanks of course to my parents, particularly for your support in purchasing Jan the van without whom my sporadic bouts of homelessness would have been significantly colder and wetter.

To the best Gang a girl could have: Alicky Davey, Sara Green, Dean Gallears, Jono Handley, and Sophie Persey. Without the confident knowledge that I always have some wonderful adventure to look forward to with you all, I'm absolutely sure I would be miserable. And without your constant above-and-beyond friendship and support there's also a significant chance I would be dead.

Thomas Hennessy Jones. You were a bit late to the party but you certainly brought the candles. I've never been so well looked after in all my life as during these months of the final push. Thank you so much for your love and belief in me, facilitating rejuvenating (if sometimes forceful) coast path walks, and for expertly knowing when I need a Negroni, some Ukulele orchestra, or a bit of both.

Finally, my dearest B (O'Brien). You have been the most wonderful, consistent, and unconditional supporter through this and I can state categorically that I would not have been able to do it without you. You should probably have your name on the front. I don't know how other people get through life without you as a best friend, but I also don't care because you're mine. If you think that finishing this PhD means I'll stop showing up on your doorstep, drinking all your gin and sleeping on your sofa you are sorely mistaken – to many more years of that.

Abbreviations and Acronyms

ADNAP	Administração Nacional das Pescas
AIC	Akaike Information Criterion
AMA	Associação do Meio Ambiente
BH	Balanced harvest
BMU	Beach management unit
BOFFFs	Big Old Fat Fecund Females
CCP	Conselhos comunitários de pesca (community fishing council)
CORDIO	Coastal Oceans Research and Development in the Indian Ocean
CPUE	Catch per unit effort
DRC	Democratic Republic of Congo
EBM	Ecosystem based management
eDNA	Environmental DNA
FAO	Food and agriculture organisation
GLM	Generalised linear model
ICCS	Interdisciplinary Centre for Conservation Science
IDEPA	Instituto Nacional de Desenvolvimento da Pesca e Aquacultura
IIP	Instituto de Investigacao Pesqueira
ITN	Insecticide treated net
KAA	Key affected area
LLIN	Long-lasting insecticide-treated net
M&M	Morbidity and mortality
MN	Mosquito net
MNF	Mosquito net fishing
NMCP	National malaria control programme
nMNF	Non-mosquito net fishing
NMP	National malaria plan
NMST	National malaria strategy
OSOL	Our Sea Our Life project
PCA	Principal Components Analysis
PMI	President's malaria initiative (US)
RBM	Roll Back Malaria
SDGs	Sustainable Development Goals
SPACES	Sustainable poverty alleviation from ecosystem services
SSF	Small-scale fishery
TL	Trophic level
UNDP	United nations development programme
UNEP	United nations environment programme
WHO	World health organisation
WIO	Western Indian Ocean
ZSL	Zoological Society of London

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1. Introduction

1.1. Problem statement

Malaria is one of the world's most prevalent and severe diseases threatening human health. Around 445,000 deaths from malaria occurred in 2016 alone (WHO, 2017b) and 3.2 billion people are estimated to be at risk from malaria globally (1.1 billion at 'high risk') (WHO, 2016). Despite good understanding of transmission and development of the disease, sub-Saharan Africa has remained a challenging area to tackle the disease and emphasis on preventative measures at the individual level has consequently increased in recent years, mainly aimed at controlling its mosquito-borne vector. Mosquito nets (MNs) have long been deployed as a key preventative measure, with distribution of long-lasting insecticide treated nets (LLINs) requiring less intensive maintenance than first generation insecticide treated nets (ITNS). Therefore LLINs are now considered best practice, though independent sales of untreated nets still occurs.

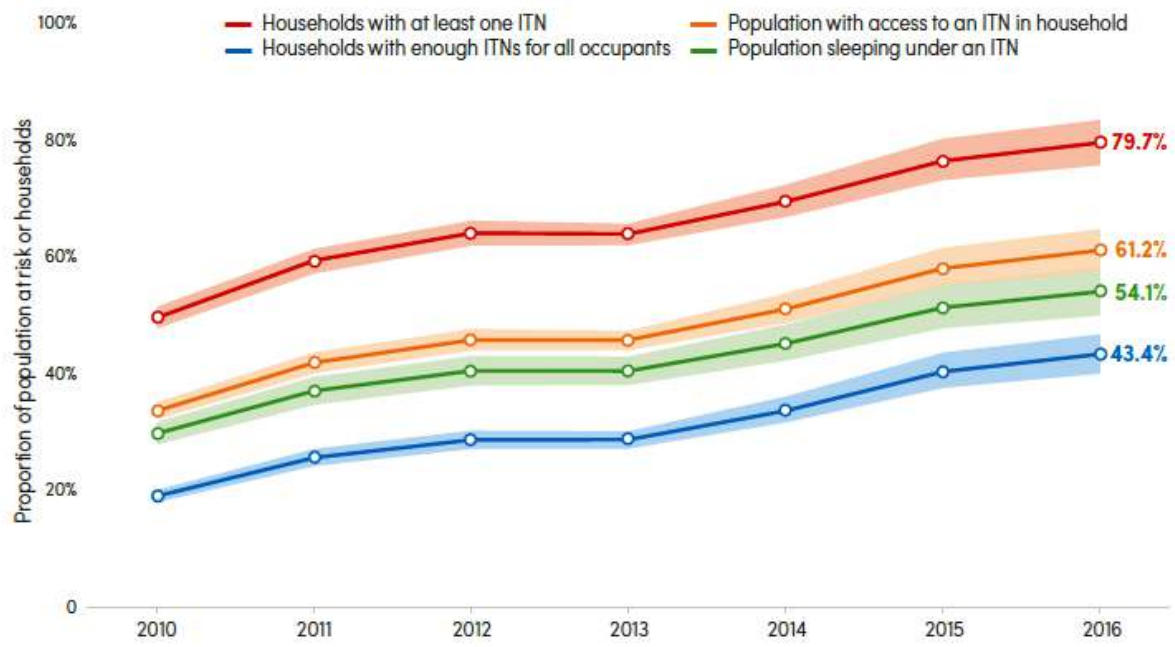


Figure 1.1. Proportion of population at risk with access to an ITN and sleeping under and ITN, and proportion of households with at least one ITN and enough ITNs for all occupants, sub-Saharan Africa, 2010-2016. (Source: WHO, 2017a)

LLINs are fine mesh (~1-3mm) polyester-based nets treated with a range of long lasting insecticides (determined by net brand), but predominantly Pyrethroids. For the purposes of this thesis I will broadly refer to LLINs, ITNs and untreated nets collectively as mosquito nets unless it is necessary to state their type. Over the last decade MN distribution policies and subsequent coverage of these nets has increased dramatically and globally (Table 1.1), with 2014 being a record year for distribution in sub-

Saharan Africa where more than half the population are now sleeping under an ITN (Figure 1.1). The World Health Organisation's (WHO) Roll Back Malaria (RBM) Programme began in 1998 with a goal of reducing malaria deaths (direct deaths and those associated with malarial complication) by half by 2010 (Nabarro & Tayler, 1998). Specifically for MNs, goals were set to ensure 80% of children under 5 and 80% of pregnant women in at risk areas sleep under nets. Distribution of MNs via the WHO malarial programme has since been largely decentralised to governments and non-governmental organisations (NGOs) where nets are intended to be supplied free of charge or subsidised.

The WHO currently recommends that organisations strive to achieve universal coverage of those considered at risk and consequently an estimated 1.4 billion nets have been delivered globally since 2004 (AMP, 2017). This emphasis on coverage is born from the success of net distribution programmes. The WHO (2014) reported that between 2000 and 2013 during the expansion of these efforts malaria mortality rates fell by 47% globally, and by 54% in the WHO African Region. Much of this success is attributed to ITNs. Consequently, the malaria-focused goal number 6 of the Millennium Development Goals was met (Target 6.C: Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases) (United Nations, 2015) and new targets are set in the Sustainable Development Goals (SDGs) (Target 3.3: By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases). Despite a recent turn around on these declines since 2016, when incidence rates began to rise, the distribution of MNs in at risk areas is highly likely to continue into the future, with programmes now employing strategies for maintaining coverage rates beyond the lifetimes of LLINs.

Table 1.1. Policies currently enacted towards malaria prevention by WHO region in 2013 and number of countries enacting them by region. Adapted from The World Malaria Report, WHO, 2014.

Policy	AFR	AMR	EMR	EUR	SEAR	WPR	Total
Nets distributed free of charge	41	19	8	4	10	10	92
Nets sold at subsidised prices	14	1	0	0	0	2	17
Nets distributed to all ages	38	18	7	3	10	9	85
Countries with ongoing malaria transmission	45	21	8	3	10	10	97

WHO regions: AFR = Africa, AMR = Americas, EMR = Eastern Meditarranean, EUR = Europe, SEAR = South East Asia, WPR = Western Pacific.

Coastal and lacustrine communities most at risk of malaria also suffer from a suite of other developmental issues; one of which is a generally high reliance on small-scale fisheries (SSFs) for livelihoods (McIntyre, Reidy Liermann & Revenga, 2016). Definitions for SSFs differ depending on social, ecological, geographic or political perspectives. For the purposes of this thesis, given the case study location, I use the Mozambican government definition of non-industrial, low-technology

operations on foot, or operating from boats <10m long with sail, oar or motorised power of <100 hp (Pereira *et al.*, 2014). Globally, SSFs contribute around half the catch according to the Food and Agriculture Organisation's (FAO) estimates, and this represents two-thirds of the catch intended for direct human consumption (FAO, 2015). SSFs are also key livelihood providers, employing over 90% of the world's fishers, but having a much wider impact on food security and economies (FAO, 2015). In addition, there is increasing appreciation for the social and cultural importance of the sector (Carvalho, Edwards-Jones & Isidro, 2011).

However, fisheries management has predominantly evolved in a system where rents are prioritised over food security under a western-centric, commercial fishing narrative which encourages rapid technological growth and investment; meaning fishing is now a thoroughly globalised system of largely elite capture (Béné, Hersoug & Allison, 2010; Cochrane, 2000; Obregón *et al.*, 2018). This narrative is increasingly recognised as perverse and particularly harmful to developing countries who lose out in in both the short and long term; centralised management policies are blamed for expanding and perpetuating inequities and the sale of the global south's fishing rights to more developed nations are appreciated as extremely short sighted (Kaczynski & Fluharty, 2002; Anon, 2011; Binet & Failler, 2011). Small-scale fishers are particularly affected as they are increasingly marginalised and conflicts with commercial fishers grow. A focus on single-species, size-based commercial fisheries management is also increasingly appreciated as highly ineffective in mixed SSFs (Kolding & van Zwieten, 2011).

SSFs in the developing world, and particularly Africa, are also under ever growing additional pressures. Expanding human populations along African coastlines are fuelled not only by local population growth, but also significant coastal migration as inland and marine resources become increasingly depleted (Riddell & Rosendo, 2015; Rosendo *et al.*, 2011; Crona & Rosendo, 2011). In many places, both coastal and inland, fishing is replacing traditional nomadic or agricultural activities as the predominant source of income (Aburto, Thiel & Stotz, 2009). New entrants to fisheries often lack experience and capital to operate and purchase technical fishing gear such as gillnets and/or vessels such as sail boats and even canoes. This can lead to an increased prevalence of dangerous fishing activities and risk-taking, overexploitation due to a lack of traditional ecological knowledge, and the use of opportunistic fishing gears (Cripps, 2009).

The distribution of free or subsidised mosquito nets (MNs) is being increasingly reported as leading to 'misuse' of these nets as fishing gear in both coastal and inland fisheries. The effect of mosquito net fishing (MNF) on bednet coverage, and therefore malaria, is in debate but remains of concern to the health community whose evaluation methods for ensuring correct use and optimised coverage of MNs are still neglecting this issue. The majority of the reports relating to misuse are based in the grey

literature or anecdotal mentions within the peer reviewed literature (e.g. Gettleman, 2015; Hopkin, 2008; Shah, 2010; Srivastava et al., 2002). Focussed studies on the drivers, extent and effects of MN fishing are significantly lacking, although piecemeal evidence related to prevalence is provided by some direct studies (Bush *et al.*, 2016; McLean *et al.*, 2014; Minakawa *et al.*, 2008; Larsen *et al.*, 2018; Mulimbwa, Sarvala & Micha, 2018), and some reviews have attempted to theoretically assess the threat (Garg, 2016; Eisele, Thwing & Keating, 2011). Fine mesh sizes (usually ≤3mm) are critical for exclusion of mosquitos, but are posited to render MNs used in fisheries almost entirely unselective in terms of small fish. Additionally, the broad availability and low cost of the nets may be leading to increased fishing pressure and competition from additional fishers entering the fishery. Social issues potentially relating to MNF include localised conflicts over resources (van der Elst, 2003), high dependence of vulnerable user groups (Bush *et al.*, 2016) and low institutional capacity for management (Cinner *et al.*, 2009), which in many cases has led to national bans on MNF (Bush *et al.*, 2016). These combined effects are viewed as a significant threat to fisheries sustainability.

There are calls to redress the balance and address issues of marginalisation and threats to food security in SSFs, dealing with the required changes from a social equity and wellbeing perspective that relates more to the provision of food and less to incomes (McClanahan, Allison & Cinner, 2015; Coulthard, Johnson & McGregor, 2011). There are additional calls to address the recent downturn in progress towards malaria elimination, and increasing appreciation that MNF impacts on malarial efforts need to be understood better (Killeen *et al.*, 2017b). Despite these movements there has been little investigation of MNF drivers and impacts, and none endorsed by global-level policy makers. Instead, at the country level, many governments have moved to ban the activity. These bans may have detrimental impacts on local livelihoods and food security in the short-term, with the most vulnerable bearing the opportunity costs of management. This critical trade-off serves as good motivation for understanding this issue and its specific impacts better for evidence-based interventions. Key questions emerging include: how does MNF interact with ecosystems? Who are the user groups (at a localised scale) and what is their socio-economic status? What are the drivers and impacts of MN use for these groups? At what scale does this fishing occur and how might external actors and market influences affect MNF? Is it socially just to focus management efforts on a gear for which there is no empirical evidence of harm to fish stocks or should we apply the precautionary principle through restrictions, at least in the short term, where risks to the fisheries are theorised?

1.2 Aims and objectives

The overarching aim of this study is to investigate the socio-economic and ecological dynamics of mosquito net fishing under a socio-ecological systems (SES) framework (Fig. 7), both globally and

within the context of the livelihoods and wellbeing of rural coral reef communities in northern Mozambique.

Objectives:

A. Characterise the current global use of MNs for fishing, from the perspectives of key stakeholders from the health and resource management sectors.
B. Using the case study of coastal Cabo Delgado, northern Mozambique, qualitatively characterise an MN fishery in depth; critically assessing the theorised impacts of MN fishing on coastal ecosystems and evaluate how MNs interact with other gear types.
C. Characterise how mosquito net fishing fits in to overall household livelihood strategies for fishers at the case study location, determining contribution of the activity toward incomes and food security.
D. Evaluate stakeholder expectations of the potential effects of management intervention strategies, holistically informing management through conceptual models of resources, research needs and policy options.

1.3 Thesis outline

In addition to this introduction, the thesis is split in to six further chapters:

Chapter 2 positions MNF within the current orthodox theory as it relates to a socio-ecological system with a focus on fisheries and health, presenting this as a conceptual model against which the rest of the thesis may be contextualised and introducing the chosen case study location within which aspects of the model will be explored.

Chapter 3 presents the results of an expert knowledge elicitation workshop which identifies policy mechanisms of relevance to MNF across the relevant sectors of public health, fisheries management, development and conservation. A synthesis of policy recommendations is contextualised within the relevant literature and a first assessment of potential interventions is presented.

The results of this chapter are in the process of publication through the Oxford Martin School's policy paper series as a policy paper and brief:

Short, R.E., Hill, N., Arlidge, W., Arthur, R., Berthe, S., Castello y Tickell, S., Coulthard, S., Lorenz, L., Sibanda, M., Milner-Gulland, E.J. Achieving net benefits: A road map for cross-sectoral policy development in response to the unintended use of mosquito nets as fishing gear. Oxford Martin Policy Paper (In prep).

RS was responsible for methodological planning and organisation of the workshop, data collection and analysis, drafting the manuscript and subsequent editing. All other authors contributed expertise to the workshop and contributed to manuscript editing. EJMG and PA were responsible for oversight for the workshop.

Chapter 4 utilises a global survey of expert witnesses living and/or working within malarial zones concurrent with fishing communities to demonstrate a first broad assessment of the prevalence of MNF. Additional qualitative data on the global variability in characteristics, demographics and perceptions of risks and benefits is also presented.

A shortened version of the results presented in this chapter appear in:

Short, R., Gurung, R., Rowcliffe, M., Hill, N., et al. (2018) The use of mosquito nets in fisheries: A global perspective. PLOS ONE. Available from: doi:10.1371/journal.pone.0191519.

RG was responsible for data collection and curation and additionally utilised the data towards her MSc thesis. RS was responsible for oversight, data analysis, the initial draft and subsequent editing. EJMG, MR and NH were responsible for oversight and edits to the draft.

Some of the data presented here are also used in the below publication to which RS additionally contributed to drafting and editing:

Trisos, C., Alexander, S., Gephart, J., Gurung, R., McIntyre, P.B., Short, R.E. (2018) Reconciling conflict among sustainable development goals: the case of mosquito net fishing. *Nature Sustainability*.

Chapter 5 is largely the result of a rapid assessment of catch landings in Cabo Delgado, presenting a comparison of catch composition across the predominant gears of the region and positioning MNF in competitive terms. This is complemented by focus group consultations with fishers to further characterise the deployment methods, target species and user groups of MNF.

Chapter 6 investigates the food and livelihood contributions of MNF to local households, both those engaged in MNF and those not. A comparison of these household groups aims to elucidate the characteristics of MNF households as well as ascertaining relative livelihood importance of the activity and determining impact on bed coverage by MNF. Focus group data lends depth to these analyses and I present the dominant perceptions of risks and benefits associated with MNF by fishing communities.

Chapter 7 provides a discussion which positions the main findings of the preceding chapters within current and paradigm shifting global agendas, additionally building on the identification of future research needs from previous chapters.

In addition, during the time of the thesis RS contributed to a draft and subsequent editing of the following associated publication:

Bush, E.R., Short, R.E., Milner-Gulland, E.J., Lennox, K., Samoilys, M., Hill, N. (2016) Mosquito Net Use in an Artisanal East African Fishery. *Conservation Letters*. Available from: doi:10.1111/conl.12286.

1.4 Mozambique: A case study

Mozambique, bordering Tanzania to the north, South Africa to the south, Zambia, Zimbabwe and Malawi to the west, gained independence from colonial Portugal in 1975. Having emerged from a subsequent 16 years of civil war just 24 years ago, Mozambique now has a population of more than 20 million with an annual growth rate of 2.5% and one of the fastest growing economies (+6%) in Africa (World Bank, 2018). However, this growth has not been felt by all with large rural-urban disparities relative to other African countries. The country still suffers the effects of prolonged conflict through poor infrastructure, an essentially two-party political system that remain in sometimes violent conflict, and a reliance on natural resource-based economics (though it is rich in these). Mozambique remains the 8th poorest country globally (United Nations Development Programme, 2017) and the road out of poverty has been made harder by a retraction of the majority of aid in 2016, including by the International Monetary Fund, in response to extreme government corruption which led to a subsequent crash in the Metical and rapid increases in the cost of living (Arndt & Tarp, 2016). Despite all this, overall poverty is decreasing with the number of Mozambicans below the basic needs povertry line halving in the last 25 years (Directorate of Economic and Financial Studies, 2016).

Mozambique and marine biodiversity

The Mozambican coastline is 2,470 km long with numerous archipelagos, a continental shelf of 104,300 km^2 and an exclusive economic zone (EEZ) representing 571,955 km^2 of the Western Indian Ocean (WIO). The inshore waters are comprised of a complex of ecosystems including sandy and rocky beaches, sand dunes, coral reefs, estuaries, bays, seagrass beds and mangrove forest (Pereira *et al.*, 2014). In terms of climate, the northern and central regions exhibit subtropical patterns with distinct rainy (Oct-Mar) and dry seasons (Apr-Sep), whereas the south tends to be drier.

Despite exhibiting high diversity, endemism and containing near-pristine environments only 3.1% of Mozambique's waters have protected area status (www.protectedplanet.net). Coastal development projects in the north of the country are mainly focused on oil and gas exploration. It has been suggested that there is limited capacity, data and incentive for proper environmental and social planning in light of these pressures, the effects of which could be catastrophic (Pereira *et al.*, 2014). Coral reefs and seagrass beds are particularly susceptible to the heightened sediment loads associated

with construction processes, potential for oil spills and the pipeline construction (http://www.offshore-environment.com/oilbedford.html). Significant reserves of graphite and rubies have resulted in mining activity in Cabo Delgado. Coastal run-off and water pollution has resulting negative effects on local marine ecosystems (Pereira *et al.*, 2014). Tourism is growing in Mozambique as it becomes a hotspot for wildlife tourism, in the marine realm in particular, and it is increasingly appreciated that improved standards and management will be necessary to ensure sustainability (Pereira *et al.*, 2014).

Coastal ecosystems are widely susceptible to the current and predicted effects of climate change. In Mozambique, this is likely to manifest in negative impacts on the vulnerable ecosystems such as coral reefs and seagrass beds from rising sea temperatures, ocean acidification and sea level rise (Riddell & Rosendo, 2015). Additionally worrying is intensification and increased frequency of extreme weather events. Coral bleaching events, which showed poor recovery levels, have occurred in Mozambique following El Nino events with up to 99% coral mortality in the northern regions (Muthiga *et al.*, 2008). Increased tropical storm frequency, causing physical damage and sedimentation of reefs, seagrass and mangroves, makes recovery from these events difficult. Similarly, extreme flooding and drought can stress estuarine and nearby coastal systems through increased sedimentation, variations in salinity and pollution from agricultural run-off (Pereira *et al.*, 2014).

The main threats to marine biodiversity in Mozambique are largely linked to its increasing coastal population and reliance on natural resources. Fishing pressure has increased according to the quadrupling of Mozambique's human population in the last 50 years. Artisanal exploitation is expected to continue to grow as the country also goes through changes associated with economic development, changing cultures and the environmental effects of climate change (Blythe, Murray & Flaherty, 2014). Additionally, trade in high value taxa such as sharks and sea cucumbers has increased with resulting population declines (Pierce et al., 2008). Commercial exploitation in Mozambique is subject to the common effects of frequently perverse international agreements and significant Illegal, Unregulated and Unreported (IUU) fishing (Lopes & Pinto, 2003). Mangroves are similarly affected by coastal population growth, as cutting for firewood, and construction purposes is removing this habitat so vital for coastal protection at a rate of up to 15.2% per year. Mangroves may also be cleared for agriculture and are susceptible to pollutants in run-off (Pereira *et al.*, 2014).

Mozambique and fisheries

Total national catches in 2010 (reconstructed) stood at 138,000 tonnes. Pereira et al., 2014 reported an increase in per capita average annual fish consumption from 4.2 kg in 2005 to 10.4 kg in 2012 despite a concurrent decline in production in the industrial fleet which can be explained by the

disproportionate growth in the artisanal sector. Reconstructed catches by Doherty *et al.*, (2015) show small-scale catches between 1950 and 2010 to more than double from 52,000 t to 108,000 t which represents 76% of the total catch, though this includes a steady decline in catches since a peak in 1982. As Mozambique has grown, it's fisheries remain predominantly small-scale relative to others in the Western Indian Ocean region (WIO), and the rural-urban equity divide which exists is felt keenly by fishing communities. These reconstructed catches also highlight exploitation rates at 4.6 times more catch between 1950-2010 than was reported to the FAO.

The most commonly used gears in artisanal fisheries are gill nets, hand lines and seine nets (Pereira *et al.*, 2014) and targets for SSFs were predominantly teleost fish (92%), and shrimp (6%) whereas industrial fisheries focused on penaeid shrimp and scads (Doherty *et al.*, 2015). Recent foreign investment in expansion of tuna fishing were unfortunately subject to corruption and failed (Cotterill, 2017). The prawn and shrimp fisheries are particularly important in central and southern regions, however significant declines in catch have been seen (-70.5% 2005-2012 (Pereira *et al.*, 2014)) and conflicts with mosquito net fishers, blamed for decreases due to juvenile capture, have been an issue (van der Elst, 2003). Commercial and high-value catches are predominantly marketed abroad, with exports to South Africa, Zimbabwe, Spain, Portugal and China important for the national economy (Blythe, Murray & Flaherty, 2013). Semi-industrial and artisanal catches, though marketed almost entirely domestically, do not currently meet growing national demand and are supplemented by imports of low-value products, largely Namibian horse mackerel (Pereira *et al.*, 2014). Artisanal catches tend to be sold locally fresh or dried due to a lack of processing facilities and transport issues, meaning prices can vary greatly, however the growth in this sector is prompting new markets to open (IDPPE, 2013). The IDPPE, 2013 census recorded a total of 280,040 artisanal fishermen, illustrating the importance of this activity to employment and subsistence. However, this likely does not capture significant additional contributions, particularly from women, for post-catch processing and marketing.

Mozambique's Ministry of Fisheries (MIPE) is responsible for management of all sectors within the EEZ, licensing, annual quotas, assessments, gear restrictions (currently only inclusive of a minimum mesh size of 2.5 cm – meaning MNs are illegal (Pereira *et al.*, 2014)) and seasonal closures. The relevant administrative bodies within the Ministry are as follows (S. Rosendo, 2017, Pers. Comms.):

- National Administration of Fisheries (ADNAP)
- National Institute of Fisheries and Aquaculture Development (IDEPA) : socioeconomic/technological development
- National Institute for Fishery Research (NIFR)

- National Institute of Fisheries Inspection (IIP): responsible for stock assessments, data collection and analysis, recommendations
- Fisheries Development Fund (FFP): mandated to facilitate credit mechanisms for development
- National Directorate for Fisheries Surveillance (DNFP): compliance with national law

Co-management systems, with village levels Fishing Community Councils (CCPs), have been encouraged in the artisanal sector at the district level in response to the challenges of assessment and enforcement (MIPE, 2013). At the artisanal level it is these councils and local authorities with on the ground responsibilities for seasonal closures, spatial protection and enforcing gear restrictions.

Mozambique is a lucrative target for IUU fishing, by both Mozambican and foreign fishers, with a long coastline and limited enforcement capacity, particularly offshore. Within the artisanal sector IUU fishing generally relates to breaking of local temporal, spatial and gear-based rules. A recent evaluation of compliance with artisanal regulations in Beira, central Mozambique, highlighted extremely poor levels of compliance and awareness, with MN fishing recorded as one of the most pervasive issues (along with unseasonal use of beach seines, which may also involve MNs as cod ends) (Darkey & Turatsinze, 2014).

Mozambique and malaria

Malaria is endemic throughout Mozambique, being the major cause of morbidity and mortality. Nearly all cases of malaria have been attributed to the *Plasmodium falciparum* parasite and the predominant entomological vectors are *Anopheles funestus, A. gambiae,* and *A. arabiensis* (Mozambique Ministry of Health, 2010). In the 2014 World Malaria report, WHO listed Mozambique within a list of eastern and southern African countries where >50% of the population has access to an ITN in their household. However, it remains a hotspot despite these efforts, with 100% of the population at high transmission risk and the 2017 report lists Mozambique as one of 15 countries accounting for 80% of cases, with a stark rise in malaria incidences since 2013; a concerning global trend which is likely due to a complex mix of factors (WHO, 2017b).

Mozambique's National Malaria Control Programme (NMCP) was formally established in 1982 in line with global targets. Though patchy small-scale campaigns and trials had occurred since 1998, mass distributions of MNs in Mozambique did not begin until 2010. By 2014 12 million nets had been distributed to add to the 4.5 million from smaller campaigns (Inform Malaria, 2018) and whilst funding for nets in Mozambique increased steadily until 2013, external funding declined from 2014-2016 (WHO, 2017b). Despite these cuts, MN distribution methods in Mozambique have advanced in recent

years, with new research in the broader malaria community feeding in to development of mapping, micro-planning, training (Arroz *et al.*, 2017) and use of education and behaviour change campaigns concurrently (Arroz, 2017).

Cabo Delgado

The case study section of this thesis was conducted in Cabo Delgado; Mozambique's northern-most province, the coastline of which falls within the East African Coral Coast (EAC) eco-region (one of three ecoregions including central swamp coast and southerly parabolic sand dunes), Mtwara-Quirimbas complex and Northern Mozambique Channel (NMC) (Spalding *et al.*, 2007). These areas have been identified as regionally and nationally important for biodiversity (Garnier *et al.*, 2012; Hill *et al.*, 2009) and have warranted recommendations for World Heritage status (Obura, 2012). These recommendations aim to protect what are some of the largest coral reefs and seagrass beds nationally. Within the WIO the region is a particularly important contributor to larval export and overall genetic mixing due to the high connectivity facilitated by internal and external currents of the Mozambique channel. The NMC has been identified as a core ecoregion for the WIO with respect to coral diversity and the second most diverse region in the Indo-Pacific (Obura, 2012), incorporating the fringing and island reefs of the Quirimbas archipelago and Primeiras and Segundas archipelagos. Additionally, eight of the twelve WIO seagrass species occur here, creating extensive nursery and feeding grounds, and the most extensive examples in the WIO of mangrove forest are found here (Pereira *et al.*, 2014). The presence of extensive reef, seagrass and mangrove habitats, the connectivity of which has been elucidated as a driver of diversity (Unsworth *et al.*, 2008), is significant for the biodiversity and species abundance of the region.

Cabo Delgado is undergoing rapid economic and social change, with recently discovered oil and gas reserves lauded as the answer to Mozambique's deepening debt crisis and expected to transform the province. Heavy investment has meant the rapid creation of road and transport infrastructure and led to the small town of Pemba, the provincial capital, exceeding its limits. Cabo Delgado is recognised as an area of particularly high density of fishing centres but with more artisanal licenses being granted in the more southerly regions. Traditionally, fishing has supported a predominantly agriculture-based subsistence system; enabling the purchase of agricultural products. This agriculture mainly consists of familial plots of land, with the predominant subsistence crops being maize, cassava (both of which are used to make the local staple of xima), beans, peanuts and to a lesser extent rice (Wosu, 2018). Commercial crops are largely limited to coconut and mango. A recent growth in importance in cash incomes for households in these villages can be largely attributed to growing markets for agricultural, but mainly fisheries, products in the local towns/cities of Montepuez, Mocímboa da Praia, Palma and

Pemba (driven by oil and gas and other extractive interests) and the further afield centres of Nacala and Nampula.

This dual reliance on fishing and farming has been problematic in recent years given that both activities have been reported to be in decline (Rosendo *et al.*, 2011). Formal knowledge of the state of small-scale fisheries and how this has changed in Cabo Delgado is lacking despite having the largest number of recorded fishers, with catch statistics for this province largely omitted from national efforts (Jacquet *et al.*, 2010). However, national-level reconstructed SSF catch showed a steady decline from 1986 following a period of rapid catch increase after independence (1975) when capacity increased (Jacquet *et al.*, 2010). These reconstruction results align with local perceptions of similar trends of decline in Cabo Delgado and analyses of localised fisheries further south on the Sofala bank where fishers largely attributed declines of fish numbers and size to numbers of fishers, intensity and methods of fishing (Blythe, Murray & Flaherty, 2013). Agricultural declines are mostly attributed to climatic change affecting amount and predictability of rainfall in the region and limiting both volume and diversity of crops (Riddell & Rosendo, 2015). These changes, alongside rapid cultural and economic change and a lack of adaptive capacity have served to increase the vulnerability of coastal communities in Cabo Delgado which experience increasing levels of poverty compared to a national decline (Directorate of Economic and Financial Studies, 2016).

Heavy Swahili Tanzanian and Kenyan influences alongside historical cultural influences from Arab traders utilising the Quirimbas islands have meant that more than 90% of the population of Cabo Delgado are Muslim, despite Mozambique being a predominantly Catholic country (Wosu, 2018). Accordingly, families are polygamous and conservative, following Islamic law which has left women highly restricted in their lifestyles and increasingly segregated, despite Bantu influences meaning matrilineal structures are retained. This can mean that an increased focus on monetary incomes further marginalises women and Wosu (2018) in her examination of female fishers in the nearby Quirimbas islands has shown women in this region to particularly lack autonomy and resign themselves to powerlessness, for example to the risk of being left homeless by divorce. As such female poverty is acute in a generally high poverty area, illiteracy rates are high at 80.6% compared to 50.8% for men (INE, 2011), and compared to the South of Mozambique where 54% of households are female headed, the stigma of not having a husband limits this to just 21% in the North (Wosu, 2018). Strict gender roles are present in livelihoods engagement, with women largely limited to the intertidal zone in terms of fisheries access. MNF has therefore been identified as prevalent in Cabo Delgado particularly amongst women (Gettleman, 2015).

The extreme economic difficulties, high vulnerability and rapid change experienced by the coastal communities of Cabo Delgado provides a potentially very stark picture of the possible risks and benefits of MNF, making this a suitable target region for a first case study investigation of socio-economic impacts. Much of the limited MNF literature has focused on freshwater systems. This Cabo Delgado case study provides critical and currently unique insights in to the issue of MNF in coastal fishing-farming economies.

Our Sea Our Life (OSOL): A co-management model

The most recent National Report on the Implementation of the Convention on Biological Diversity to the CBD (MICOA, 2014) recognises the importance of Mozambique's unique and diverse biodiversity to human and economic development, but also the critically endangered status of most of its 12 ecoregions and an increasing number of endangered species. The reversal of threats from habitat loss, overexploitation, invasive species, pollution and climate change are impeded by institutional capacity, slow integration of conservation goals amongst other priorities for decision-makers and implementation of an existing (but new) legal framework for biodiversity protection. Funding for field conservation, capacity building and inter-institutional co-ordination is a key underlying driver.

In response to these challenges, Our Sea Our Life (OSOL; Nosso Mar Nossa Vida locally) is a five year collaborative project between the Zoological Society of London (ZSL), Coastal Oceans Research and Development in the Indian Ocean (CORDIO), Associação do Meio Ambiente (AMA), Bioclimate, Universidade Nova de Lisboa, and Universidade Lurio towards addressing these issues (https://www.zsl.org/conservation/regions/africa/our-sea-our-life). The goal of OSOL is to secure resilience of coastal ecosystems and wellbeing of local communities in Cabo Delgado province through establishment of Locally Managed Marine Areas (LMMAs) and implementation of co-management initiatives.

The Mozambique Ministry of Fisheries has, at the policy level, encouraged devolution of artisanal fisheries management to local communities through co-management legislation, encouraging the formation of CCPs (Community Fishing Councils). These in turn are supported by provincial and local government who should provide expertise and training, to manage and enforce their local fisheries. Co-management aims to make management more locally relevant and accepted, encouraging broad stakeholder buy-in and aiming for sustainable incentives for conservation of resources through improved livelihoods (Jentoft, McCay & Wilson, 1998). A recent analysis of social and ecological success in protected areas showed a crucial relationship between conservation and socioeconomic outcomes, challenging the total exclusion of people as best for conservation (Oldekop *et al.*, 2015). Protected areas reporting positive social outcomes are more likely to report positive conservation outcomes. Co-

management systems which empower local people, reduce inequalities and maintain cultural and livelihood benefits are more likely to produce positive conservation outcomes (Oldekop *et al.*, 2015). In a review of 42 co-management efforts in coral reef communities, Cinner et al., (2012) concluded that there is strong evidence for positive social and ecological outcomes widely across systems (livelihoods benefits, good compliance and greater fish biomass). The authors outline the predominant factors of success as: deep understanding of human roles in ecosystem declines; co-management is sustained and established; and when resource users are wealthier. The latter point can have negative effects such as polarising communities if this increasing wealth is not equitable, hence the need to ensure equity and inclusion of marginalised groups.

However, legislation and implementation of these CCPs and co-management processes in Mozambique remains limited and unclear. These failings are not limited to Mozambique and have been documented in co-management efforts elsewhere, as outlined in Bene et al., (2010), as a function of lack of investment and lack of institutional capacity at these devolved levels. In this case, a focus of the OSOL project is supporting provincial government in implementing co-management, development of spatial management plans and LMMA structures whilst also empowering communities and marginalised groups through innovative development solutions. In the Cabo Delgado province of Mozambique, women are particularly marginalised from what are likely to be universally inadequate fisheries management efforts, and this could be theorised to be amplified if a woman is also a MN fisher due to the illegality of the activity. There is a need to include all user groups (illegal or not) in co-management efforts. Chuenpagdee and Jentoft, (2007) also highlight the importance of understanding the processes preceding formation of co-management plans, which is perhaps particularly relevant for spatial management and where stakeholder relationships are particularly complicated.

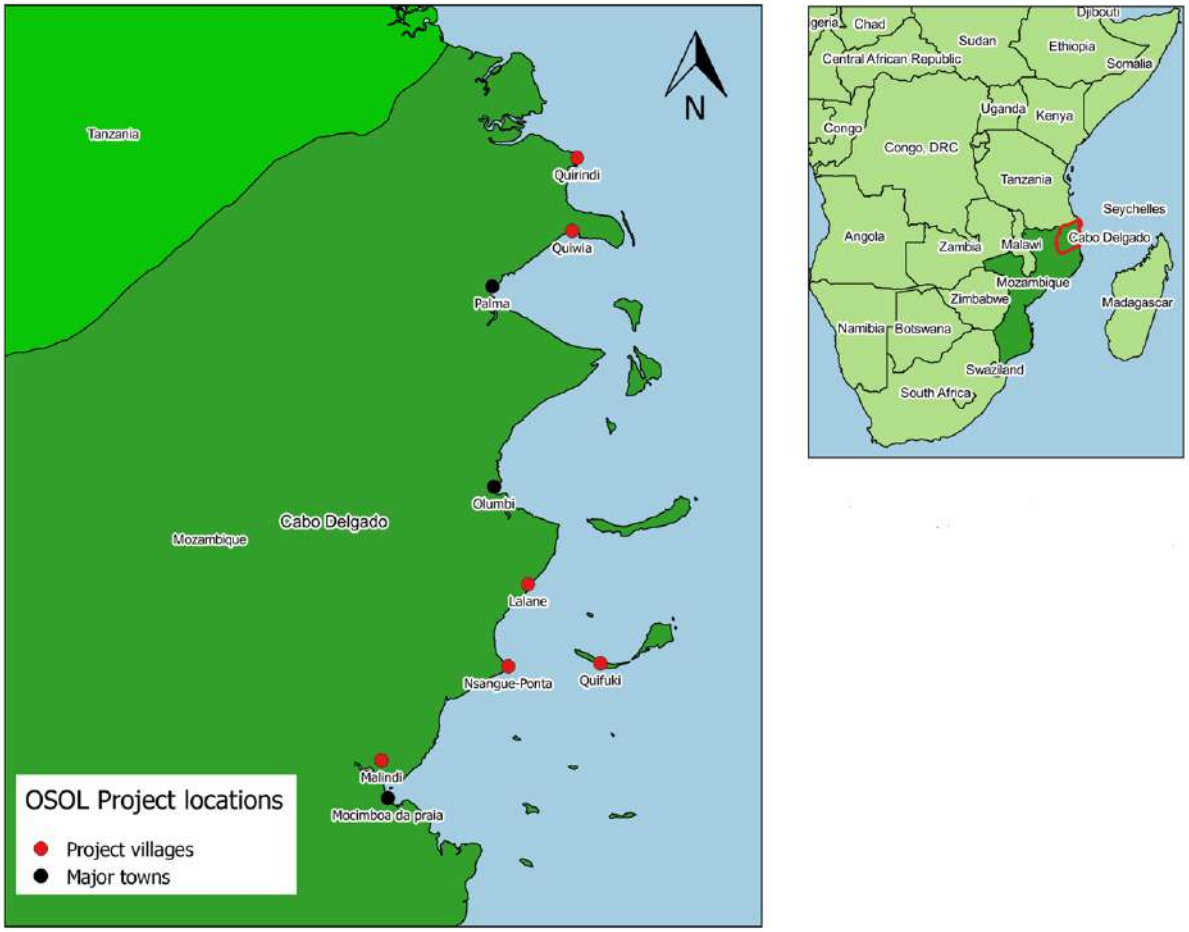


Figure 1.2 - Map of Cabo Delgado showing location of 6 villages included in OSOL project

The OSOL project has operated over six villages between the town of Mocímboa da Praia and the Rovuma river and Tanzanian border. All villages are coastal, barring one island community, and diversification of livelihoods outside of fishing (including gleaning) and farming is limited. Preliminary studies conducted by the OSOL team and reported by Rosendo (2016, unpublished) showed that at mainland sites just mat making (from local palm fibres, largely sold outside of the villages) and small artisan food businesses (bread making, cake making, food 'cafes') contributed in any significant way to occupations and this varied amongst sites. The villages of Malinde and Qurinde showed two of the highest levels of diversification at 2.6 and 2.9 occupations per household (which was the highest of any village). Between 70% and 94.7% of households actively farm (excluding Quifuque which is a trading island site), with Malinde representing the highest end of this range. Fishing prevalence demonstrates similar numbers, highlighting the importance of dual occupations, with up to 94% of households engaging. Although households in Malinde and Quirinde showed lowest levels of fishing at 76.3% and 74.3% they demonstrated the highest levels of MNF at 42% and 24% of households respectively which justified their use as case study locations (Samoilys *et al.*, 2018, In press) (Figure C.5). All sites had active community fishing councils (CCPs), however, Quirinde and Malinde's CCPs were established prior to

inception of the OSOL project, consequently having a lower level of input from project staff. Both CCPs were considered to be ineffective at the time of the survey, with no management plans or active enforcement in place.

In general, subjective wellbeing in the OSOL sites is currently low amongst both men and women. Rosendo (2016) found rates of satisfaction with quality of life to be as low as 37% amongst households. The vast majority of households allotted most of their dissatisfaction to a lack of economic security and ability to meet basic needs and many people linked this directly to their ability to farm successfully, particularly worrying about changing climatic conditions and poor soils. This has driven an increased interest in fishing activities, despite a broad appreciation of fisheries as an equally declining resource.

To begin to work towards better social equity, opportunities for diversification and resilience in these villages the OSOL team have promoted establishment of Village Savings and Loans Associations as part of overall enterprise development. VSLAs were pioneered by CARE International in Tanzania as an innovative micro-financing mechanism aimed at bridging the gap between such schemes and access for the rural poor (Allen, 2002). VSLAs are independent (i.e. without access to banks or external financing), time-bound accumulating savings and credit associations. Groups save regularly together according to their income and choices (in a shares-based system). This central pot is then open to short term (1-3 months) loan applications be repaid with interest. An 'action audit' is then undertaken after all loans are repaid, whereby the resulting assets are divided up amongst the group according to each person's shares (Anyango *et al.*, 2007). This model therefore offers two means of accruing assets; both through investments using loans and also the group's accumulated interest. VSLAs are an effective mechanism for encouraging livelihood diversification and opportunities to decrease dependencies on natural resources, particularly for women (Karlan *et al.*, 2017).

Cabo Delgado, as a low population province most distant from the administrative centre of Maputo has often been side-lined in MN distribution efforts. The OSOL sites did however receive a mass distribution from the government and aid agencies in 2014/15 (Arroz *et al.*, 2016) and have received another in 2017 (Arroz *et al.*, 2018). In addition regular small-scale distributions are made through healthcare centres by The Aga Khan Foundation (Aga Khan, 2018). MNF was highlighted as a serious issue in the region of particular relevance to women, and so this project was identified for suitable case study facilitation for this thesis. Whilst initial investigations conducted by the OSOL team did focus on livelihoods generally, little information on the drivers and impacts of MNF were identified. It was clear from the project's inception that MNF was a critical issue for CCPs and that the will, capacity and understanding necessary to address the issue was not currently sufficient. The results of this thesis will inform approaches to MNF within the co-management development in Cabo Delgado, with lessons for

the wider region, and was conducted concurrently with these implementation efforts. There is, therefore, an influence of the developing co-management relationships on the research which is accounted for wherever possible; i.e. sites were chosen based on low levels of influence, consultation with the OSOL project team was consistent throughout the research and whilst I was introduced to communities as a partner of the OSOL project it was made as clear as possible that I remained an independent observer.

It should also be mentioned that since inception of this research and the OSOL project outlined below, Cabo Delgado has suffered from a rapid rise in violent insurgency originating in the town of Mocímboa da Praia, which has directly impacted the OSOL sites and halted activities since October 2017. This increasing violence, some of which has been focused on the case study villages, has also halted oil and gas activities in the region and its impacts for local people are not well understood (Morier-Genoud, 2018).

1.5 Ethical approvals

Chapter 4 (online survey)

Ethical approval for this chapter was granted through the Imperial College's MSc in Conservation Science's research ethics process, involving formal review and approval by a committee of Faculty members. All responses were anonymous unless the respondent chose to identify themselves. No questions required information which could identify individuals engaging in MNF and all personal information relating to respondents was available only to the authors. Quotes are only used with consent from respondents. Detailed location data (at a resolution finer than 1 degree or with descriptive information) are available only on application to the authors and based on the undertaking that fine-scale locations are not identified in subsequent analyses.

Chapters 5 & 6 (focus groups & household survey)

Ethical approvals for these chapters were granted through the Imperial College Research Ethics Committee (ICREC). Ref: 15IC3005 10/11/2015.

All datasheets, questionnaires and consent forms were designed by myself followed by a consultation with local OSOL staff and a one-week pilot phase. Interviews were conducted only with free confirmed prior informed consent (FPIC) and all respondents were ensured anonymity to enable honest discussion on the illegal activity of MNF. FPIC forms were designed for both literate and illiterate respondents. All intermediary enumerators were given training in the importance of FPIC, anonymity and data protection prior to engaging in the survey. All datasheets were reviewed by myself on a daily

basis and regular check-ins with enumerators were used to identify any issues with either the methods or the responses from the community. Accordingly, there was an English speaking research assistant in the villages accompanying me at all times. Two or three teams of two were deployed dependent on the situation and I would alternate between groups twice daily to ensure there were no issues. Enumerators were only turned away from one household and the reasons given were displeasure at previous visits from an NGO offering free seeds which did not materialise. All data was kept in a locked house during data collection and anonymised immediately upon my return to the UK.

2. What's the hang up with mosquito net fishing?

A conceptual framework

2.1. Introduction

There is a glaring dearth of targeted MNF research, with much of the current knowledge hidden away as mere mentions in reports, papers and books focused on other topics. The earliest such mention in the published literature is from Manila Bay in the Philippines in 1987 where the authors briefly describe a cubical lift net (Silvestre & Federizon, 1987), but is even earlier in the grey literature in 1980, when a triangular push net made with MNs was described, also in the Philippines (Motoh, 1980). Both accounts very briefly describe the target catch as shrimps and small pelagics but here the detail ends. These types of brief accounts continued (supplemented by one or two fisheries reports inclusive of MNF) until around 2007 when media articles begin to appear proclaiming the dangers of MNF, culminating in the now well-known New York Times piece in 2015 (Gettleman, 2015). Targeted publications began in 2008 but are thus far limited to about 6 studies which focus on case studies (Eisele, Thwing & Keating, 2011; Larsen *et al.*, 2018; McLean *et al.*, 2014; Minakawa *et al.*, 2008; Bush *et al.*, 2016; Mulimbwa, Sarvala & Micha, 2018) or in the case of Garg (2016) a simple review of the limited literature. For the most part these publications have also come from one or other of the relevant disciplines, with little or no collaboration across sectors and therefore are limited in scope. Inferences on actual impacts of MNF, positive or negative, are not generally robustly enabled by these papers, with the studies positioned more like initial investigations of MNF and it is clear that a holistic assessment of the necessary research is long overdue.

One significant problem arising from this dearth of empirical research is that the rhetoric surrounding MNF has been largely dictated by the media and has been overwhelmingly negative, despite being based almost exclusively on anecdotal information and not scientific evidence. For example, in his 2015 New York Times piece Jeffrey Gettleman describes MNF as a pan-African and increasing problem, highlighting both the unsustainable catches and pollutant effect of insecticides despite no large scale survey confirming the former and little evidence supporting the latter statement. Reactions, which are likely at least in part a consequence of media reports have included introduction of prison sentences for MNF offenses and violent conflicts between fishers. There is a clear need to widen the net on

empirical investigations of MNF and a holistic review of the potential drivers and impacts will be critical in directing the early stage of this research.

Here I review the current orthodox concepts of particular relevance to MNF, drawing on research across public health, conservation, natural resource management and sociology, amongst other disciplines. I both critique those potential impacts which are causing alarm amongst conservation and health communities, whilst also exploring ideas which support the potential for positive impacts of MNF. Synthesising these theories, I present a conceptual framework of a potential socio-ecological system inclusive of MNF on which further discussion and research can be built.

2.2. What drives concerns over mosquito net fishing?

Ecological drivers & the severity issue – why is MNF deemed so damaging?

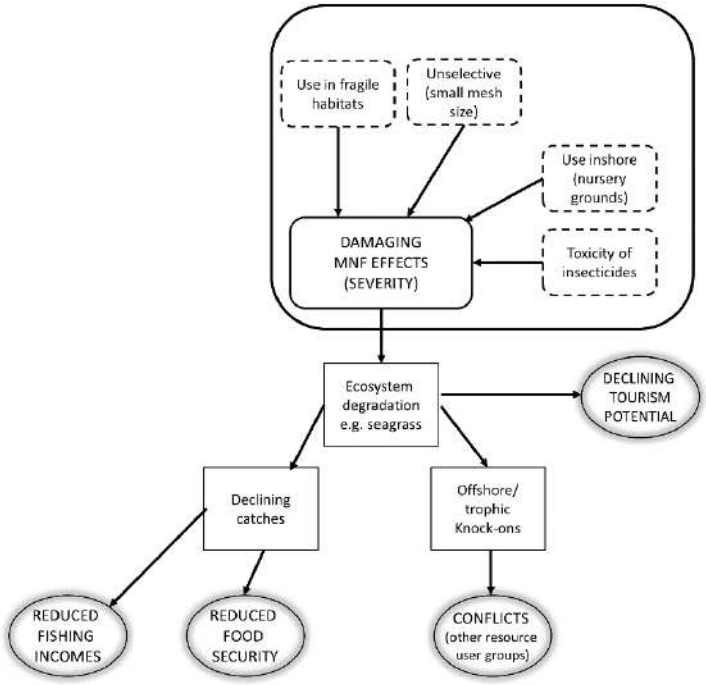


Figure 2.1 - Aspects of MNF related to severity and consequent impacts

Central to the concerns over the use of mosquito nets for fishing is their mesh size; the amount of space between the individual strands of a net and therefore the relative sizes of fish or other aquatic organisms that may be caught or allowed to pass through the net. The general mesh size for a mosquito net is ~2mm with a recommended minimum of 156 holes per inch^2 (Roll Back Malaria, 2001), dependent on the material and area of use.

This small space for escapement has led to MNs being commonly referred to as indiscriminate, i.e. capable of catching most sizes of organisms inclusive of adults, juveniles, larvae and indeed even eggs (Bush *et al.*, 2016). In reality a number of other factors such as spatial and temporal deployment methods are involved in a gear's selectivity (Huse, 1996). The predominant, current fisheries management paradigm globally is grounded in maximising selectivity, both in terms of species and individual size (Breen *et al.*, 2016). Operationally, this dictates that fishers should aim to catch individuals of a length over a pre-determined 'size at first maturity'. This strategy relies on the assumption that the majority of these

individuals will be at a mature age and therefore are likely to have had a chance to breed and contribute to the recruitment of the population prior to capture (Sissenwine & Shepherd, 1987). But sizes are also based on the goal of optimising the outputs from the fishery and minimising Growth overfishing. This essentially aims to optimise 'rents' from a fishery, but can also be seen to aim for the maximum wet weight of protein and therefore food security, usually on a species-specific basis (Diekert, 2012). As biomass and age relationships are non-linear there are optimum size ranges within which you may harvest individuals to ensure these maximum outputs (Diekert, 2012). Mesh size management is one of the main ways this is implemented (Liu *et al.*, 2016). Mosquito net mesh sizes are too small to ensure these management objectives for most species and therefore is considered to potentially contribute to a risk of overfishing.

We know very little about the actual impacts of fine-mesh gears empirically, and even less specifically about MNF. Small mesh gears such as lift nets and many traps are already widely used in many parts of the world, particularly Asia (SEAFDEC, 2018; Silvestre & Federizon, 1987; Upadhyay & Singh, 2013), but even these mesh sizes are often viewed as unsustainable. The difference between just 5 and 10mm mesh sizes has been noted to have significant impacts on sustainability in some fisheries (UNEP, 1999), with the smaller mesh size deemed more harmful. Some empirical insights may be gleaned as to the impacts of fine-mesh fisheries from the glass eel and shrimp fisheries of Guadalquivir, Spain which use 1mm and 5mm mesh sizes respectively. An investigation in to bycatch in this fishery concluded significant community-level impacts due to impacts on the estuary's nursery function (Sobrino *et al.*, 2005), but represents a somewhat extreme case where these nets are used at scale. Although there are few fisheries that can be compared to the use of mosquito nets in terms of mesh size, any fishery targeting fish below size at first maturity could be seen to have a similar effect, so the fine-mesh size issue is still highly debatable.

The scale of MNF as related to ultimate impacts is also an issue of deployment methods, although these are poorly documented. MNs lend themselves well to be used in many ways, in many habitats and at many scales. Although use as a small seine net seems predominant in the literature (Bush *et al.*, 2016; Gough *et al.*, 2009; Samoilys, Maina & Osuka, 2011), some more large scale beach-seining has also been reported (Tietze, 2011). Traps may be a more common use for very fine mesh sizes like MNs, either reinforcing existing traps or leading to innovative designs (Pravin *et al.*, 2011).

Whilst fisheries management can focus on species and populations when it comes to managing selectivity, it is also important to consider the health of the ecosystem as a whole and therefore the physical impacts of gear use on relevant habitats (Mangi & Roberts, 2006). Without a healthy system, populations are far less able to recover from stochastic events, impacts of climate change and

overfishing. There have been numerous reports of use of mosquito nets in mangroves, seagrass beds and even on coral reefs, with the nets used as a seine and dragged over the surface (Gough *et al.*, 2009; Samoilys, Maina & Osuka, 2011; Tietze, 2011). These critical habitats already suffer from significant threats due to trampling, sedimentation, pollution and deliberate removal. Additional damage from the use of mosquito nets and associated activity (increased footfall and trampling) is cause for concern. These habitats are also important in terms of connectivity to one another and support to populations at differing life history stages, providing nursery grounds and refugia for many fish species and therefore fishing within them may have a disproportionately negative impact on sustainability (Unsworth *et al.*, 2008).

Negative impacts on tourism livelihoods in developing nations have received attention in recent times due to the global economic crisis and shown to particularly impact those with high dependency – women, foreign workers, those with dependents (United Nations Global Pulse, 2011). Whilst tourism has its impacts, sometimes significant, it also serves as a strong incentive for conservation of natural habitats and sustainable management of resources to cater for visitor needs (Diedrich, 2007). General mis-management of, for example, coral reefs can negatively impact both existing and potential future local incomes from this industry through degradation of the attractant wildlife/ecosystems. Destructive fishing techniques which serve to destroy coral reefs, such as blast and cyanide fishing, can have such an effect and it has long been appreciated that broad stakeholder buy in is key to success in eco-tourism (Pet-Soede, Cesar & Pet, 1999). The role mosquito nets might play in this degradation should be of consideration in areas of current or developing tourism interest, with consideration to the balance of immediate vs. long term livelihoods and equal access to these livelihoods central to considerations.

Plastic pollution is of great concern globally, particularly those entering the marine environment (Koelmans *et al.*, 2014) where consequential breakdown renders the resulting 'microplastics' capable of entering the food chain and acting as chelating agents for harmful chemicals to both people and wildlife (Teuten *et al.*, 2007). A 2014 review estimated the per capita contribution of LLINs to domestic plastic use to be just 200 grams per year (WHO Global Malaria Programme, 2014). However, this equates to more than 100,000 tonnes of eventual waste plastics with residual insecticides. In countries such as Kenya, Rwanda, Botswana etc. where plastic reduction is taken very seriously and even plastic bag bans have been introduced, this 200g increase is of significance. A lack of overarching policy on disposal of the millions of nets that are gradually becoming unfit for purpose means monitoring is not a priority and dearth of information exists on their fate and the potential impacts. Certainly in coastal and lacustrine areas there is a real risk that discarded nets may make it into aquatic systems. Discarded nets of all sorts, on beaches and at sea, have long been an ecological threat. When floating free at sea

the nets may continue to catch fish or entangle other species with no benefit to people, where they rot in the nets, an issue known as 'ghost fishing' (Matsuoka, Nakashima & Nagasawa, 2005). They are also a troubling vessel for invasive species when floating over long distances, enabling further spread of the associated threats to native species. Build-up of discarded nets on beaches in places such as the Philippines is a huge issue, contributing to small mountains of plastic that clog the local environment.

There is also legitimate concern linked to residual insecticide remaining on the nets entering aquatic systems. Pyrethroids are currently the predominant class of insecticides used on MNs, with Permethrin the most commonly used. Pyrethroids are known to be toxic to a broad range of aquatic life (Hill, 1989) and we have little to no understanding of what levels of leaching may occur from MNs in the varying habitats at risk, nor the impacts of currents/littoral systems on in-water concentrations or bio-accumulative effects. Whether or not pyrethroid insecticides are of concern to aquatic populations, resistance to these chemicals by mosquitos is driving development of new net treatments. One proposed such treatment in 'next generation nets' is Chlorfenapyr (N'Guessan *et al.*, 2016), a pesticide that is highly toxic to humans though little is known about levels of toxicity conferred by nets (Kang *et al.*, 2014). If these nets are to become the norm, then a better understanding of how these chemicals are transferred via fishing and drying of fish on MNs will be necessary.

Socio-economic drivers & fisheries under pressure - understanding the trade-off to engage

Public knowledge of the transmission processes involved in malarial infection is not universal amongst populations at risk of contracting the disease, but is high and increasing (Mwenesi, 2005). Similarly, there is evidence to point towards high levels of understanding of the potential impacts on sustainability of fisheries amongst users (Bush *et al.*, 2016) therefore we might infer that to engage in MNF is often an informed decision. Certainly the idea that this malaria or fishing trade-offs largely favour fishing in poor communities, for both current and non-traditional fishers alike, is quite a key concern for the future impacts of this activity (Honjo & Satake, 2014). When considering MNF's contribution to overall impacts on a fishery, accounting for the fact that many fisheries were suffering from issues before MNF became a central concern, overall pressure (number of fishers and consequent number of dependents) on the resource is certainly a factor and there is a need to understand both the quantity and drivers of 'new entrants' to fisheries who may be encouraged to do so by MNs, alongside drivers of fishing effort. It is just this expansion of the total numbers of people engaged in a fishery and how much they may fish that introduces another threat to the fishery; recruitment overfishing. This overexploitation of fisheries resources is a result of unsustainable fishing effort, whether that fishing is selective or not, where so many individuals are removed from a population that the spawning stock and therefore consequent recruitment is significantly reduced (Pauly *et al.*, 2002).

This can lead to stock collapse, with knock-on impacts to other fished and unfished populations, and is associated with intensive and commercial operations, but is increasingly an issue in artisanal fisheries compounded by damaging fishing habits and environmental change.

We only have a basic understanding of the scale of MNF, both in terms of global prevalence, but also in terms of the amount of effort exerted at the local level (numbers of people engaging and frequency of engagement), partly because the illegalisation of the activity means it is often excluded from monitoring efforts so critical to informed management. A small number of case studies exist where localised prevalence specifically of MNF was assessed: Darkey and Turatsinze, (2014) locally reported that 100% of fishers (surveyed on beaches, not equivalent to households) in two areas of Beira, Mozambique were found to employ mosquito nets as fishing gear and McLean et al. reported 87% of households admitting to using mosquito nets for fishing along Lake Tanganyika. A recent qualitative study in Zambia has reported MNF as widespread and frequent in Western Province, Zambia (Larsen *et al.*, 2018). Bush et al., 2016 demonstrate a case in Kenya where use for fishing by 50% of households had no recorded impact on bed coverage and use of old or damaged nets proliferated despite high levels of access to nets. Although difficult to infer actual prevalence of use for fishing, a survey of seven fishing beaches on Kenyan Lake Victoria for LLIN use for drying fish revealed 72 that had been used for fishing in 2008, less than two years since broad scale distribution began in the region (Minakawa *et al.*, 2008). Mulimbwa, Sarvala & Micha, (2018) recently estimated MNF yields of the small Clupeid *Limnothrissa miodon* larvae from 17 sites along the DRC side of Lake Tanganyika at 24.5 tonnes, which if correct may certainly legitimise concerns surrounding effort. In a review of potential causes and consequences Garg (2016) points to the dearth of information on this issue and asserts that, were the misuse rates demonstrated in these studies to be as widespread as indicated then millions of people could be foregoing protection in order to avoid starvation.

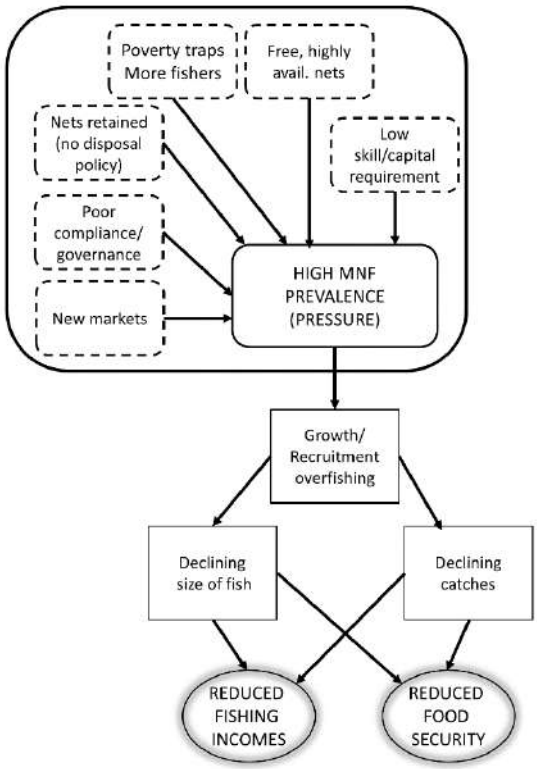


Figure 2.2 - Aspects of MNF related to overall fishing pressure (numbers of fishers) and consequent impacts

Also inhibiting a holistic view of the prevalence of MNF is our limited understanding of the trade-offs involved in deciding whether to use a net for protection or for fishing. The contribution of mosquito

net fishing (and longevity of this contribution) to localised livelihoods and food security is unknown. Understanding the divide between opportunism and dependence will be critical to planning successful interventions. In two theoretical studies Honjo & Satake, (2014) and Honjo *et al.*, (2013) have shown the decision making between 'correct' use and 'misuse' of mosquito nets to be a complicated trade-off involving local economic and social development contexts, and showing that understanding this decision making can guide effective interventions.

In this section I consider the possible socio-economic push and pull factors involved in the decision to fish with a freely distributed LLIN specifically. As the drivers here which relate to net distribution and availability are extremely complicated, ultimately requiring a separate analysis but summarise d here, I map these drivers to a generalised lifecycle of a LLIN to make this relevant to policies which may influence this decision making (Figure 2.3). I therefore assume the ultimate counterfactual would be 100% usage on beds driven by an unimpeded desire to both protect ones-self from malaria and preserve aquatic resources in to the future.

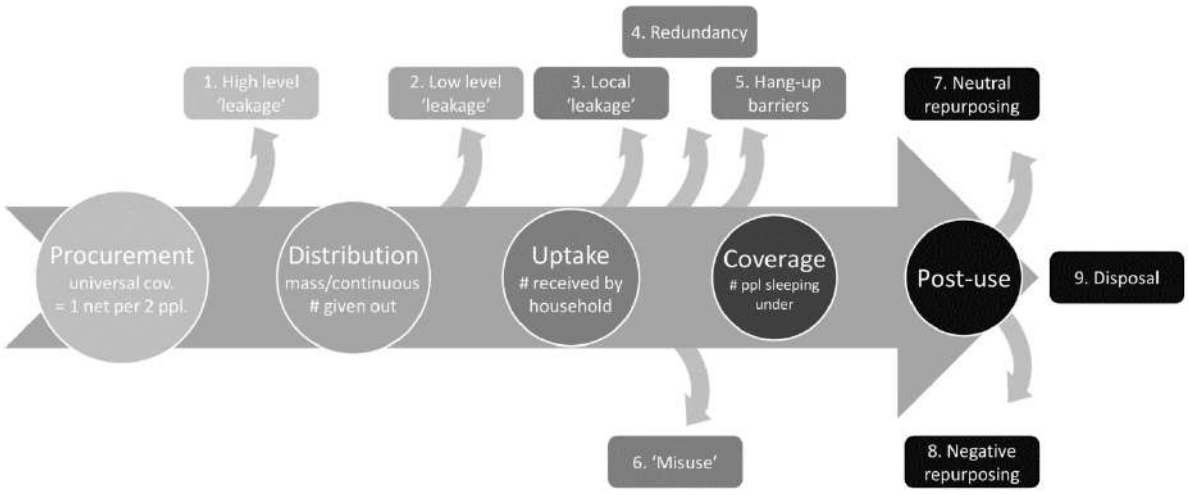


Figure 2.3 - Generalised life stages of a LLIN with events relevant to management, potential modes of net leakage (attrition) and end of life possibilities.

Oversupply and availability

The current policy adopted by the WHO regarding mosquito net distribution is a goal of 'universal coverage'. Universal coverage recommendations are 1 net for every 2 people at intervals of no more than three years in mass campaigns, alongside continuous distribution campaigns for those most at risk (e.g. pregnant women and children <5yrs) (WHO, 2014a). This has so far equated to 1.4 billion nets globally, the over-allocation of which is estimated to be as high as 21% of those distributed (Bhatt *et al.*, 2015b). There is a continuous stream of decommissioned nets for those replaced after 3 years, the importance of which we will discuss later. This issue of localised availability or localised 'oversupply'

and the mechanisms behind it are more complicated than just this initial 1-for-2 policy problem; piecing together different anecdotal and peer-reviewed information reveals that there are several points along the chain from manufacture of a net to the point at which it becomes unfit-for-purpose wherein the value of the net as fishing gear may have an impact on ultimate coverage (Figure 2.3). There have been anecdotal reports of corruption in several countries at the procurement to distribution stage (Figure 2.3, No. 1) where government officials have been accused of siphoning off mosquito nets for private sale and a level of net 'leakage' occurs. Similarly this may happen at a provincial or further decentralised stage (Figure 2.3, No. 2). Local leakage may feasibly occur through private sale of nets by individuals or households, though I could not find any targeted studies focusing on this.

Once nets reach households there are a great number of potential influences on whether or not they make it on to the beds of household members (coverage rates) which can be thought of in four broad categories (Figure 2.3, Nos. 3-6). Localised leakage may occur for similar reasons earlier in the distribution chain (Figure 2.3, No. 3), if demand exists locally a person may be able to sell their few, free nets to others locally. But similarly this leakage can be well motivated, such as gift giving to family and friends which wouldn't necessarily impact overall coverage rates (Koenker *et al.*, 2014). Over-allocation of nets because of inaccurate pre-surveys (Figure 2.3, No. 4), poor policy and indicators used or aggregated distribution can lead to redundancy (Bhatt *et al.*, 2015b; Kilian *et al.*, 2010) which may make new nets more available for alternative uses such as fishing.

Barriers to hanging mosquito nets over beds

Much effort has been expended addressing the issue of barriers to hang of mosquito nets (Figure 2.3, No. 5), i.e. households which have but do not sleep under a mosquito net, but this remains an issue (Pulford *et al.*, 2011). A lack of appetite for altering the design of nets to suit various scenarios has meant that the standard rectangular design proliferates (Kaplan, 2007). This poses numerous practical problems in hanging due to the need to anchor four points, making this difficult in circular dwellings, for those sleeping in large groups in one living space, those sleeping outside or travelling away from home, and requiring hanging material such as string (Baume, Reithinger & Woldehanna, 2009; Iwashita *et al.*, 2010; Pulford *et al.*, 2011; Toé *et al.*, 2009). The nets are often seen as unfavourable in hot weather, with poor air flow (Pulford *et al.*, 2011). Treated nets may elicit minor allergic reactions for some and fears still exist regarding health risks to children within some populations (Baume & Marin, 2007). Social barriers have also been shown to impact coverage such as when sleeping in public spaces, a problem in scenarios such as large religious gatherings or journeys (Monroe *et al.*, 2014). A lack of education regarding transmission of malaria in some cases can also lead to low coverage rates, with users either ignorant of the mosquito vector, perceiving malaria to be low risk, few mosquitoes to be

present, or for the net to be no longer useful if the insecticide has lost efficacy (Baume, Reithinger & Woldehanna, 2009; Pulford *et al.*, 2011; Thwing *et al.*, 2008). This ultimate rate of coverage may also be seen to be impacted by longevity of nets and motivations to wash dirty nets or repair minor tears and holes, and therefore the barriers to this also affect use (Toé *et al.*, 2009). Factors 3-5 in Figure 2.3 may all be seen as 'push' factors for mosquito net fishing, barriers to their intended use which may be enough to tip the trade-offs relevant to poverty and food security to the fishing side. It is important to note that many of these barriers have been known as an issue for some time and numerous efforts have and are being made by the vector control community to address them.

Misuse – a poverty reduction strategy

'Misuse' of mosquito nets for fishing and other uses is potentially the ultimate and most controversial social and economic driver of MNF (Figure 2.3, No. 6). These misuses are not limited to fishing, but include use as crop protection, chicken coops (Minakawa *et al.*, 2008), building material (Mutuku *et al.*, 2013), and famously, wedding veils (Gettleman, 2015). However, here I will discuss misuse purely in terms of its influence in fisheries. In many areas such as East Africa, which are undergoing significant social and economic pressures, there are combined pressures of coastal migration, natural population growth and diversification of livelihoods which serve to increase numbers of fishers (Aburto, Thiel & Stotz, 2009) and which may push people in to MNF. These factors are often driven by declines in alternative livelihoods, most notably in traditional agriculture but also activities such as bushmeat hunting and other uses of inland resources, even declines in opportunities for skilled labour (Riddell & Rosendo, 2015; Rosendo *et al.*, 2011). Agricultural productivity is being impacted globally by issues related to climate change and unsustainable practices such as desertification, drought and flooding. Added to this, predominantly patrilineal and matrilineal inheritance systems under growing population pressures in developing nations can serve to unsustainably divide land ownership (Jayne, Chamberlin & Headey, 2014) and tends to disproportionately impact women, even in matrilineal systems (Meinzen-Dick *et al.*, 2017).

In small scale fisheries the paradigm has long been that fishing is an 'occupation of last resort' or 'safety valve' for many who are either displaced from other occupations or lacked any initial opportunities (Onyango, 2011). Consequently a Malthusian view of the linkages between exploitation of fisheries, population growth and resulting poverty has been pervasive (Béné, 2003). This paradigm has been successfully challenged in a number of cases where fishing as a chosen (not forced) livelihood provides more than just economic benefits but contributes broadly to cultural, social and psychological wellbeing (Blythe, Murray & Flaherty, 2014) and where small-scale fisheries act as a 'bank in the water' for poverty alleviation (Béné, 2009). However, in the case of MNF, the significant opportunity costs of

engagement derived from both increased risk of exposure to malaria and the risks associated with engaging in illegal behaviour would suggest that MNF may indeed be an activity of last resort.

Underpinning MNF as a last resort, and likely to have a significant impact on prevalence and pressure of MNF, is the accessibility of the gear and fisheries resources that may be targeted. Kremer (1994) highlights a flaw in the reference to fisheries as an open access resource, stating that the significant entry costs associated with purchase of gear, skills development and societal barriers renders them far from open access to most. In these cases fishing cannot be seen as a "fall back" activity but one from which the poorest find themselves excluded. However, the rise of MNF may demonstrate that fishing can act as a fall back activity. To fish with a MN you need no form of capital investment, as nets are free. No seafaring knowledge or indeed fishing experience is necessary; MNs can be used to good effect in waist-deep water, on foot or with static methods such as traps. Therefore it can be theorised that MNF may appeal strongly to those most poverty-trapped, with the fewest resources and most lacking in alternative options. Conflict and political instability may be another factor, in regions where people have been forced to leave their permanent residences or live covertly, a portable, unobtrusive and easy to conduct activity like MNF may help to get through difficult periods. Potentially more important is the influence of cultural aspects of MNF, namely the acceptable use by women in a number of societies where traditional fishing activities may be off limits as 'men's work' (Kleiber, Harris & Vincent, 2015). This engagement of people traditionally excluded from fishing (including women, children and unskilled new entrants with low capital resources), the intricacies of which are discussed later, has the potential to greatly impact the overall prevalence of MNF and therefore pressure on fisheries.

MNF may also appeal to those engaging in other activities or using other fishing gears but who are increasingly impacted by environmental, climatic and social change. Abbott & Campbell (2009) support the notion that MNF increases at times of food scarcity and income insecurity from both fishing and agricultural instabilities. Intertidal fishing during times of hardship has long been a coping strategy of the coastal poor, traditionally with the use of cloth nets (Bush *et al.*, 2016; Samoilys, Maina & Osuka, 2011). Indeed, as catches associated with legal and more established gears decline, there have been numerous well documented moves towards destructive and less selective methods from current fishers, even such as dynamite and cyanide fishing (Muthiga *et al.*, 2008; Pauly *et al.*, 2002). MNF may also represent a form of 'fishing down the food web' (Pauly *et al.*, 2002). Abbott and Campbell (2009) also stress the importance of diverse livelihoods, particularly in dynamic environments such as estuaries where environmental variability can be one of the main temporally variable stressors for those engaging in fishing. This is reinforced by Blythe et al. (2014) with specific reference to coastal Mozambican fisheries, where they found the most influencing livelihood stressor to be, as predicted,

declining catches. However, they also found other significant stressors to be socio-economic (disease) and ecological (storms and drought) creating similarly dynamic environments that may drive a move towards low-cost and easily accessible fisheries such as MNF. In these cases it is possible that MNF could play the role of a safety net, providing immediate returns income and food sources that serve to enhance resilience from reliance on predominantly delayed-returns activities such as agriculture (Torell *et al.*, 2010).

A final potentially positive influence of MNs on aquatic resources and livelihoods is through their reported use in aquaculture. Evidence of their use in various stages of the aquaculture process has existed for some time, notably capture of wild fry with which to stock grow-out ponds in Asia e.g. in Bangladesh (Rahman, 2008). These efforts naturally target juvenile fish, but as Rahman notes in this study, this doesn't necessarily pose a threat to wild populations, and aquaculture may actually relieve pressure on wild fish particularly as fry sources transition over to hatchery-production with time. MNs may also be used in freshwater aquaculture for the construction of 'Hapas'; small, static hatcheries for production of species such as Catfish, Carps and Tilapia (FAO, 2007).

It's no longer fit for purpose and I don't know what else to do with it

The final phase in the life of an ITN is what happens to it once deemed no longer fit for purpose as a bed net. This is usually due to excessive tearing/damage and is the scenario we consider here, although it can be due to a perception that the insecticide is no longer effective. Some studies have suggested that the predominant nets used in MNF are those deemed 'old' or 'used' in terms of bed coverage (Bush *et al.*, 2016; Eisele, Thwing & Keating, 2011), whereas other studies have suggested that damaged nets are not seen as effective for fishing and therefore new nets are preferred (Minakawa *et al.*, 2008). In terms of impacts on both prevalence of MNF and the potential health impacts of reduced bed coverage it will be important to determine this at the local level. Old nets used for fishing could be deemed to have a negligible direct impact on malaria prevention. However, cumulative build-up of these old nets as mass distributions continue will increase the availability of nets for fishing is significant.

One major factor in the decision of what to do with an old net, is your ability to safely and efficiently dispose of it. The WHO's current policy on disposal of nets no longer fit for purpose is currently limited to advising safe incineration or, as a last resort, burial of nets (WHO Global Malaria Programme, 2014). However, this document also places the onus of disposal on governments in countries where waste management is often already extremely challenging and doesn't take into consideration issues such as incineration capacities and modes of collection of nets. Additionally there is a lack of evidence on the suitability of burial as a policy in terms of environmental risks from insecticide leaching. Generally,

distribution programmes offer little advice to end users on effective disposal. In a recent study of net repurposing in Kenya, Kibe et al., (2015) report a lack of guidelines for disposal to be one of the main reasons cited by end users for repurposing old nets, a small percentage of which were used for fishing. Additionally, the authors found that inappropriate burning and disposal of nets which ended up 'scattered everywhere' was more likely to occur in urban settings where alternative uses were rarer, with the local waste disposal authority yet to provide any guidelines or interventions for collection and disposal of old nets. Even if nets are not used for fishing by those disposing them, the open waste disposal of many rural cultures may allow collection of discarded nets from other households for MNF, further exacerbating the issue of high supply.

This dearth of effective policy on the disposal of nets has received some research attention regarding contributions to insecticide resistance (Norris et al., 2015) and changes to biting behaviour (to focus more on those not protected) (Moiroux et al., 2012) driven by MN use and particularly the preservation of nets in the environment beyond their useful anti-malarial life. Currently the barriers to effective disposal lie with development of an affordable model for collection, identifying either incineration facilities at an appropriate scale or recycling opportunities, determining acceptable levels of residual insecticide (dependent on plausible recycling uses) (Nelson and Rack, 2012) and local buy-in and willingness to give up old nets (Ramanantsoa et al., 2012). A piece of anecdotal information which puts this information in context was derived from an NGO working on the shoreline of Lake Malawi in 2016. Having successfully imposed a local by-law against the use of mosquito nets for fishing, and developed a model of enforcement which involved set-up of local fisheries councils, the authorities were eventually left with a large number of confiscated nets for which there was no disposal mechanism. As the nets had been altered for fishing they were no longer fit for bed nets, and the NGO were of the impression that there were no incineration facilities that could cope with the volume of nets, even at a national level (Geoffrey Furber, Ripple Africa, Pers. Comms., 2017).

2.3. The combination of a severe and prevalent issue; the feedbacks

Poverty traps & conflicts

Degradation of coastal resources and their management has been cited as the clearest example of breakdown of institutional resilience, often due to property rights issues and lack of management of common pool resources (Adger, 2000). The use of MNs for fishing is an example of a potential positive feedback scenario for resilience in coastal social and ecological systems; whereby poor fishers resorting to MNF are further poverty trapped by consequent declining resources. This may inhibit economic mobility; where incomes are declining or persisting at such low levels that people are unable to invest in strategies to improve their lives in the longer term (Cinner, Daw & McClanahan, 2009). While MNF

is hypothesised to have potentially devastating effects on fish stocks and can therefore be seen as a cause of overfishing, it is also the inherent declining productivity of traditional fishing activities along with population growth that can drive use of alternative gears and methods such as MNF, making it concurrently an effect of overfishing.

Illegal gear often increases conflicts where shared resources are perceived as at risk, particularly when access rights are deemed to have been infringed at international and domestic levels (Calas & Martinon, 2010). Introduction of new and damaging fishing methods by itinerant fishers or locals can be particularly divisive and may even lead to violence. These kinds of conflicts are not uncommon and can be difficult to resolve once biases become entrenched (Pomeroy *et al.*, 2007). Although the study was never published in its entirety, van der Elst, (2003) documented a serious case of conflict in the Nampula province of Mozambique. Commercial shrimp trawlers attributed declines in shrimp populations to inshore fishers using mosquito net lined gears. High juvenile capture rates (11% of the catch by weight) had led to a new 'cottage industry' of deep-fried larval shrimp and fish on roadsides. The artisanal fishers in turn accused the trawlers of fishing too close to shore and encroaching on their resources. Eventually a compromise was reached whereby trawlers stayed offshore and artisanal fishers removed the mosquito net liners, although this was later challenged as to its efficacy as a policy.

Future issues could include the cultural changes and gender biases involved in the use of mosquito nets. Part of the accessibility associated with the activity comes from its acceptance as 'women's work' and/or open to all genders and classes. These changes can cause frictions in themselves, but have also been known to shift as resources in general decline and markets change. Examples have been documented of displacement of women by men from 'new' activities as they gain traction and value: the rise of male seaweed farmers in Tanzania responding to new markets was followed by a rapid decrease in market value of the products due to investment influx (Williams, Williams & Choo, 2002); and as octopus markets expanded men were able to exploit this previously female-dominated resource at deeper and more distant locations, ignoring traditional harvest periods which lead to overexploitation (Porter *et al.*, 2008). These kinds of gender-based divides are exacerbated by a generally lower literacy rate and access to education for women, also linked to cultural discrimination and time poverty for activities towards improved wellbeing (Bennett, 2005). These barriers can impact women's ability to formally organise, ability to trade, financial and market-based understanding. With numerous anecdotal reports of mosquito net use by female fishers the importance of mosquito net fishing to women is in need of investigation and our understanding of this may significantly affect what are considered viable management options.

Health processes

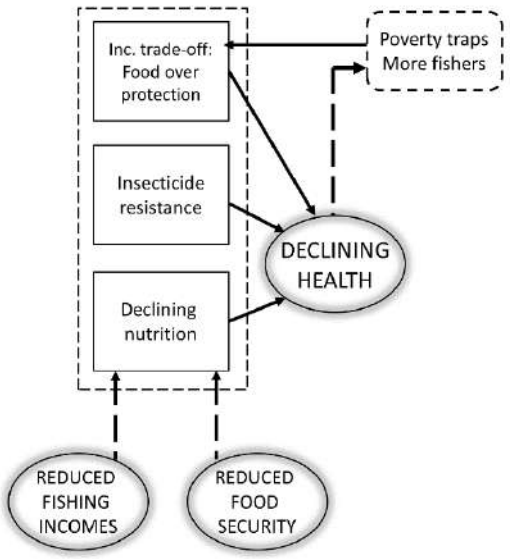


Figure 2.4 - Direct and feedback impacts associated with MNF relevant to human health and malaria prevalence

Globally, the malaria-focused target under the Millennium Development Goal (6) was met for 2015 with 55 countries on track to reduce burden by 75% (WHO, 2014b). However, since 2013 incidences of malaria have begun to creep back up even in the African region where net distribution is focussed, though mortality continues to fall (WHO, 2017b). This increase is likely to be due to a complicated picture inclusive of funding declines/inequity, humanitarian crises/conflicts, climate change, and some declines in the use of other vector control methods such as Indoor Residual Spraying (IRS). However there is also some recognition that a pervasive reliance on MNs as the predominant vector control method may be short-sighted (Killeen *et al.*, 2017b). Overreliance on mosquito nets for malaria prevention may be problematic because: a) as malaria rates fall it is hypothesised people may be less incentivised to use their nets for sleeping; b) resistance to permethrin insecticides is globally on the rise; c) distribution efforts are still not equally resourced across all at-risk countries and; d) of course nets may be used for alternative purposes. It is possible that the highly fundable and PR-strong and initially impactful act of distributing nets has led the global community to neglect both implementation and development of the other tools for malaria control (Killeen *et al.*, 2017b, 2017a).

Exactly how alternative use of nets impacts on trends in malaria prevalence, in terms of bed coverage rates and consequently malaria prevalence, is not fully understood and indeed current indicators are largely ineffective proxies for one another. A recent study from the VectorWorks group at Johns Hopkins (VectorWorks, 2018, presentations available online) suggests that numbers of nets employed in MNF may be insignificant in terms of bed coverage (as low as 0.06% of nets). However, others express significant concerns for the impact of this alternative use on malarial rates particularly at the local level and particularly where poverty drivers of MNF are acute (e.g. Banek et al., 2010). These concerns are of potential significance largely because of the importance of the 'community effect' when specifically adopting LLINs as a malaria reduction strategy. It has been shown that at and above threshold levels of MN coverage, the mortality rates of mosquitoes coming in to contact with the insecticide treatment have a population-level impact on the vector (a mass community effect) which

translates to a reduction in malaria transmission beyond those directly protected (Howard *et al.*, 2000; Killeen *et al.*, 2007). If these threshold coverage rates are not achieved, for whatever reason, then this effect is lost.

As the number one cause of death in countries such as Mozambique (29% of hospital deaths, morbidity and mortality; Mozambique Ministry of Health, 2010) malaria is inherently tied to poverty. Socio-economic status has been linked to malarial risk in children, with the negative feedback effect that the costs of the disease have on generating poverty traps discussed in a meta-analysis by Tusting et al., (2013). Although the majority of mortalities occur in under 5s, and therefore economically inactive individuals, a particularly pertinent consideration is the impact of morbidity on productivity and knock-on impacts on family members from care-giving and loss of family members; therefore social and economic costs. At the household level, time and monetary investment in treatments and/or funerals, resulting opportunity costs (e.g. education) and knock-on social problems (e.g. grief, psychological consequences) all serve to perpetuate the vulnerability of households, and ultimately communities, limiting the ability to accrue assets and invest in longer term (and sustainable) livelihood strategies (Pattanayak *et al.*, 2006). In many cases this can push relatively prosperous individuals and households in to poverty. Not only are these households suffering economic hardship more likely to turn to 'desperate' activities such as MNF, but recent studies have also linked poor health to increased direct reliance on natural resources and engagement in unsustainable fishing practices. Particularly methods that can be operated inshore and require less travel and energy (Fiorella *et al.*, 2017); key characteristics of MNF and therefore an additional potential feedback.

Finally, the impact of reduced fish-derived food security and nutritional status on human health is of increasing interest globally (Golden *et al.*, 2016). This is true for both malarial prevalence and morbidity rates. In a review of global malaria burden in children under 5 by Caulfield et al., (2004), both underweight children and those deficient in certain micronutrients were more likely to contract and subsequently die from malaria. Micronutrients of note included vitamin A, zinc, and iron, all of which are important derivatives of a fish-inclusive diet (Thilsted *et al.*, 2014). Vitamin A and Zinc contributions remain important throughout life and supplementation has been shown to significantly reduce malaria attacks, alongside general protein malnutrition being closely associated with greater malaria morbidity and mortality (Shankar, 2000). In communities most dependent on aquatic food resources for their nutritional needs, ensuring the sustainability and accessibility of these resources is arguably as important a tool in the anti-malarial toolbox as MNs – a notion which is somewhat ironic when considering the potential impacts of MNF.

2.4. Socio-economic processes - what about the benefits?

Accessibility and equity in small-scale fisheries

The aforementioned availability of MNs and ease of use for fishing, as well as acceptability within cultural norms has the potential to disproportionately benefit disadvantaged and/or marginalised groups such as the elderly or disabled, and particularly women who are often subject to gender-based societal barriers. Women are widely involved in fisheries, particularly in post-catch and less 'formal' gleaning activities, the importance of which to the local economy and food security has been largely underestimated until recently (Kleiber et al., 2015) but has now be shown to be extremely important (Harper *et al.*, 2013). However, extractive activities in many developing regions remain largely operated by men and women are excluded for cultural reasons. Similarly, due to gender-based marginalisation women are often excluded from institutional frameworks such as credit systems and opportunities for increasing their assets, such as purchasing fishing gear thus excluding them for economic reasons (Béné, 2003). The importance of the role of women in fisheries, as well as a need to both recognise and capitalise on this for sustainable development purposes is increasingly incorporated in to management discourse (Bennett, 2005; Harper *et al.*, 2013; Kleiber, Harris & Vincent, 2015; Williams, Williams & Choo, 2002). However, with limited practical application the issue has recently been highlighted as still in need of critical attention (Obregón *et al.*, 2018). MNF may well circumvent some of these socio-economic barriers; free nets requiring no investment; no need for seafaring experience or access to a boat with the dual impact of making it culturally acceptable; access to inshore resources reducing travel time and ability for children to accompany mothers reducing both the effects of time poverty and the need for childcare provision. This opens up an alternative resource particularly for women and other marginalised members of society, thus explaining the frequency with which women are cited as engaging in MN fishing.

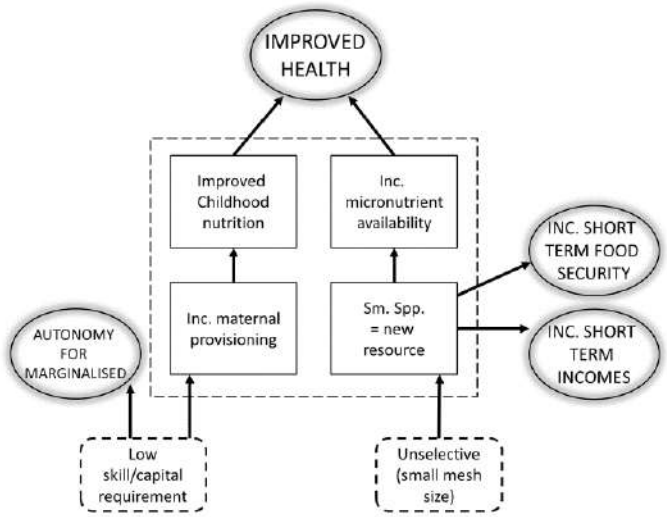


Figure 2.5 - Theorised socio-economic benefits to user groups from MNF

There are knock-on benefits to this engagement of women in MNF. Female autonomy, through provision of income and food independent of men is posited to contribute markedly to increased rates

of development as money is more likely to be invested in education and improvements to quality of life than that provided by male counterparts (Harper *et al.*, 2013). Maternal provisioning also tends to contribute more to household nutrition, particularly that of children which may even impact childhood survival rates (Ranis, Frances & Alejandro, 2000). The domination of women in this activity also presents further sustainable development opportunities, as the organisational and collaborative social norms involved are well suited to development of co-management and alternative livelihood initiatives.

A new resource

As a wider benefit across sectors of society, MNF may indeed be viewed in some instances as providing access to a new resource for new and established fishers, as well as those secondarily dependent on fish markets for food. Whether or not this resource is sustainably harvested, as I will discuss later, it may at least in the short term be viewed as a new opportunity with some evidence that species and life history stages not previously exploited, or not exploited in large quantities, are targets for MNF. These targets are predominantly reported to be small-bodied species or individuals which would often be seen a less commercially valuable and indeed are often missed in records, however may be more valuable in other ways (Kolding & van Zwieten, 2011). A supporting area of research for potentially significant contributions of mosquito net fishing to health and development is the impact on nutrition of consuming small-bodied fish in their entirety. As previously mentioned, provision of micronutrients such as Zinc, Iron and Vitamin A from fish-inclusive diets is increasingly appreciated as important, and this has been shown to be particularly so when fish are consumed unprocessed (with viscera) which is common with small fish and is of particular benefit to children (Kawarazuka & Béné, 2011).

Small fish are also easily sun-dried. This ease of preservation avoids a loss of profits due to spoiling of fish and avoids a need for storage or processing facilities which enables engagement of rural and inaccessible communities in wider markets. The subsequent ease of transportation means that these fish are also reliable sources of protein for populations far inland or distanced from water bodies (Kolding, van Zwieten & Mosepele, 2015). These catches may be having a far larger and wide-ranging food security impact, both in real protein mass-terms and also in terms of nutritional quality, than is currently appreciated. These factors also mean that, once dried, these catches can increase significantly in value and provide a decent income in a short time frame.

2.5. Bringing these concepts together

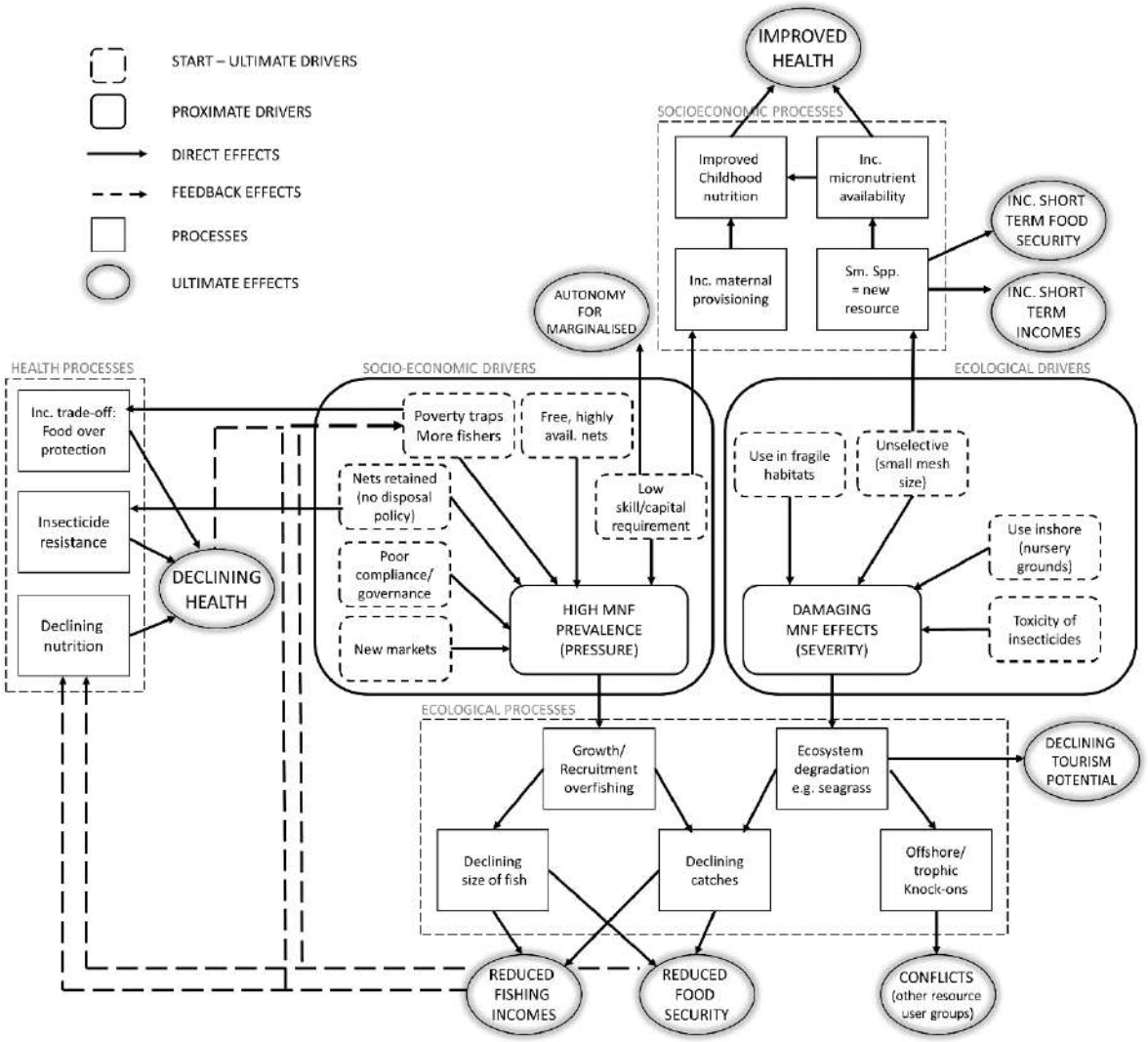


Figure 2.6. A holistic conceptual model of potential impacts and feedbacks from MNF based on current orthodox concepts in published and grey literature.

Bringing these potential drivers and impacts together in a unifying framework clarifies the possibility of numerous positive feedbacks in the Socio-ecological system pertaining to MNF. Figure 2.6 summarises the ideas I have thus far presented and I will use this conceptual model to guide much of the rest of this thesis and in investigating the validity of the assumptions that feed in to the framework. A key aspect of this framework is that it is built on the theories which underpin current fisheries management; selective fisheries management. Before empirically exploring the relevant aspects of the framework in ensuing chapters, I will briefly discuss the potential of newer management paradigms to impact the potential outcomes in Figure 7; namely that the positive benefits of MNF are purely short term.

2.6. Are all benefits of MNF purely short term?

The economic goal of fisheries management reflects traditional ecological goals – achieving Maximum Sustainable Yield (MSY), usually by managing individual species/stocks/fisheries on rolling quotas. However, over time numerous weaknesses in this approach have been documented in commercial fisheries, but particularly in complicated artisanal fisheries where many of the principles, assumptions and methods are difficult to apply (Caddy & Cochrane, 2001). As a consequence, at the 1992 UN Conference on Environment and Development (UNCED) principles were agreed upon towards a more holistic ecosystem approach to fisheries (EAF in FAO guidelines but more commonly ecosystem-based management, EBM). FAO guidelines have since been developed which aim to 'take its focus in fisheries management but broaden the perspective beyond seeing a fishery as simply "fish in the sea, people in boats" and "balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries" (FAO, 2009). For the first time broad ecosystems and human interactions were to be included in management and planning with methodologies much more aligned with resilience thinking. Whilst there is still a place for single species and stock assessments, the growing literature on effective implementation of EAF means it is now a widely accepted goal (Bianchi & Skjoldal, 2008; Browman *et al.*, 2004; Hutubessy *et al.*, 2014; Plagányi, 2007; Pomeroy *et al.*, 2010; Zhou *et al.*, 2010).

The collective movement to take a step back and look at fisheries management from the perspective of multiple scales, interactions, stakeholders and ecosystem functions has been a catalyst for shifts in other paradigms. One such change has been to investigate diversification of exploitation beyond what is traditionally important (mainly commercially) in terms of target species and sizes. Management has long focused on striving for ever-better selectivity in fishing gears, enabling specific species, groups and sizes to be caught. This tenet has been based on the ideas that i) reducing incidental bycatch of unwanted species will help preserve ecosystem integrity and ii) target species should not be caught at so small a size as to inhibit their growth (and protein) potential (yield per recruit reduction = growth overfishing) and should be caught at a size where they have been allowed to spawn and contribute to recruitment (reduced spawning potential = recruitment overfishing) (Law, Kolding & Plank, 2013). However, this has been gradually challenged as to its fit with the objectives of EAF, specifically achieving best yields, ensuring resilience and avoiding negative effects of selection pressure. From a size-selectivity point of view, the selective effects of removal of the old and fecund individuals can result in truncation of size and age structures (Blanchard *et al.*, 2005) as well as early maturation with concurrently lower fecundity at the individual level, and skewed sex ratios (Marshall et al., 2003). These factors combined can certainly contribute to destabilisation of populations, therefore increasing risks

associated with the use of MSY and the impacts of stochasticity on relevant equilibria (Garcia *et al.*, 2012).

From a species-selectivity point of view, historical choices for target species have been based largely on commercial value rather than simply nutrition and yield (Maxwell *et al.*, 2012; Pinsky *et al.*, 2011), even in developing world fisheries, as a market-driven process. This has generally meant a focus on high trophic levels, large size classes, and conforms largely to the tastes of developed-world consumers. Consequently research has highlighted an effect of 'fishing down the food chain' as successive trophic levels become depleted and technological developments allow targeting of alternative, deeper and less accessible species (Pauly et al., 1997).

While an objective of fisheries management should be to avoid bycatch of particularly vulnerable species or those inappropriate for human consumption (often requiring more specialist gear adaptations e.g. TEDs or circular hooks), the basic selection tenet has been hypothesised as flawed in balanced harvest theory (BH). The idea of BH, whereby harvesting happens across all components of an ecosystem at pressures relative to their productivity, would nullify the idea of bycatch as something to be avoided, instead incorporating it into a management strategy (Garcia *et al.*, 2012). The theory serves not only as a response to the evidence of negative impacts of the selectivity paradigm, with recent evidence supporting an ability to reduce fisheries induced evolution through BH (Law & Plank, 2018) but also to a need to maximise sustainable yields towards meeting global food security needs. Garcia et al., (2012) suggest that practical implementation of BH could be achieved by use of ecosystem-focused tools such as size-spectrum slopes for which acceptable levels would be agreed, a notion support by a number of others (e.g. Rochet et al., 2011).

The concept of fishing across ecological niches and trophic levels is gaining traction, though the specific implications for fisheries management, to promote less selective methods, remove discarding policies, or manage different gears to complement one another in time and space, is still to be determined in individual systems. Strict caution is necessary and the need for in depth knowledge of individual ecosystems is highlighted by McClanahan, (1995) when modelling reef-level responses to various fishing scenarios and pressures on yields and coral growth. This study found that a strategy of targeting just piscivores and herbivores at moderate pressures, but avoiding invertebrates, was the only scenario not to suffer either decreased yield or negative ecosystem impacts. Conversely, a number of studies (such as Jacobsen et al., 2013; Kolding et al., 2015a; Law et al., 2012) have proposed that the highest yields may be achieved from unselective fishing when looking purely at size-based exploitation patterns, and that fishers' decision-making uninfluenced by management may already be facilitating a balanced harvest (Plank *et al.*, 2017). However, selectivity is only one part of the picture, and Rochet

et al. (2011) emphasise a need for more combined studies of both pressure (effort) and community structure when investigating appropriate scenarios.

A limiting factor in development of balanced management strategies continues to be the market-driven nature of exploitation. The growing argument for a wider range of catch components producing higher yields will only serve as a benefit if these components are marketable. In the commercial sector this may mean necessary creation of incentives and efforts to change tastes (Zhou *et al.*, 2010). However, an increasing number of studies posit that BH is likely to be highly appropriate in multi-species, multi-gear systems where value is placed more on food security contributions, such as artisanal and developing world fisheries (Garcia *et al.*, 2012; Kolding *et al.*, 2015; Zhou *et al.*, 2010). Fishing patterns in these systems have organically evolved to be flexible in terms of spatial patterns, gear use, seasonality and target species, with less skew from consumer preference for specific sizes, aspects which have been viewed as opposing good management (Law, Kolding & Plank, 2013) but which are potentially valuable systems on which to base development of BH strategy. Analysis of whether BH is currently occurring in these fisheries, and at what exploitation level this may remain sustainable, would be complimented by an evaluation of the complexity of achieving an appropriate balance over the size spectra within individual case studies, particularly with reference to fisheries operating in poor data and management environments.

The issue of MNF serves as a case study wherein almost any size fish has an economic or wellbeing benefit in certain communities and, when considering the catch size spectrum in isolation, may represent what is described by Zhou et al., (2010) as a responsible model of fishing. In a recent assessment of an unregulated, open access fishery versus a regulated fishery (the Zambian vs. Zimbabwean sides of lake Kariba) Kolding *et al.*, (2015) empirically demonstrated for the first time that the regime lacking management and most resembling a balanced fishery (achieved by use of a large range of mesh sizes and gear types) produced the highest yields (inclusive of juvenile offtake) with the least impact on community structure. Of particular concern in the literature has been juvenile capture associated with MN fishing, and therefore discussion has focused on mesh size. However, in light of such arguments for BH it could be argued that the real danger of MN fishing lies in increasing pressure on the fishery as opposed to the lack of selectivity. Indeed, this utilisation of juveniles, which would otherwise experience high natural mortality rates with no human benefit, could be viewed as rather entrepreneurial. Kolding *et al*. (2015) describe the response of fishers to declining stocks in this unregulated fishery as "a logical and necessary reaction of individual fishers to gradually decrease their mesh sizes to maintain an acceptable catch rate," which could be perceived as an understandable driver of mosquito net fishing. The authors noted that the result was an increasing catch of small fish

over a wider range of species, something which would normally set alarm bells ringing and a type of catch which some audiences would consider less valuable.

BH remains of great debate and a number of valid concerns have made their way in to the literature, concerns which those who see potential value in this theory advocate should be addressed scientifically (Garcia *et al.*, 2015). These concerns fundamentally question both the theorised sustainability and the feasibility of implementation in terms of policy and are by no means minor. However they mostly relate to westernised commercial systems and may not apply to many artisanal scenarios;

- Low technological and administrative feasibility of being able to effectively harvest multiple species in a way which conforms to individual harvest rates ('micro-management') → largely not successfully done in artisanal scenarios anyway and evidence to show that this may happen organically (Plank *et al.*, 2017) would seem impracticable.
- Opportunity costs in terms of high value species which are currently considered well managed under a size-at-entry, single species regime would have to be weathered by some actors with many species/size harvest rates likely to reduce whilst others increase → a smaller issue when wet weight of protein may be valued over high-value catch and less likely to cause conflicts in mixed-species and mixed-gear fisheries.
- A predicted drop in total, global fisheries value as lower value species dominate (Andersen, Brander & Ravn-Jonsen, 2015) and harvesting costs increase for commercial scale operators (Burgess *et al.*, 2015) → artisanal fisheries are already of lower economic value and may preferentially choose this model.

If considering hypothetical management of MNF, in a scenario where concerns surrounding selectivity have been addressed, then as with any other gear type an issue still lies with levels of fishing pressure as discussed earlier. To manage this there needs to be an immediate focus on deciphering the drivers for increased mosquito net use. Underpinning arguments for the validity of BH in small-scale mixed-gear fisheries is the assumption that fishing effort in these fisheries are largely governed by natural production, something that can be challenged by commercialisation and introduction of external market influences and technology. As reviewed earlier it will be important to appreciate both push and pull factors in locally relevant contexts. Are some or all of MN fishers new entrants to the fishery? If so have they been pushed in to the fishery by external factors (e.g. migration, agricultural decline, conflict and instability) or attracted by new markets and high catch rates? Are some or all of MN fishers those switching from other gears? If so is this in response to declining catches or the lure of profits? Or a mixture of the above? It will be important to answer all of these questions to a) establish management

bearing in mind the aforementioned complexity of impacts and b) understand and predict future changes under different social as well as ecological scenarios.

2.7. Accessibility and equity in *global* fisheries

Protein consumption is estimated to increase by ~100% by 2050, however this increase is expected to be mostly driven by increased wealth leading to high protein diets, as opposed to increased numbers of people consuming necessary levels of protein (Tilman & Clark, 2014). This predicted future would likely position BH as an undesirable option to developed nations who control access to the vast majority of aquatic resources and from which demand would likely continue to conform to the current consumption culture i.e. large bodied and high trophic level species. Therefore, at a global level this is unlikely to do anything to address the looming food security crisis facing the developing world. Ensuring equity (fairness) in access to fisheries resources at a global level has been highlighted as key to ensuring food security and sustainable development, indeed it has recently been suggested that enhancing equity in systems currently failing to may be more impactful in terms of sustainable development than direct livelihoods improvements (Franks, Booker & Roe, 2018).

Equitable access to aquatic resources has relevance to almost all Sustainable Development Goals (SDGs), in particular Goal 14; 'By 2030, increase the economic benefits to Small Island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism'; and 'Provide access for small-scale artisanal fishers to marine resources and markets'. These goals similarly apply to inland fisheries but constitute goals we are currently not on target for, with achieving equity posited as a key challenge for future management (Obregón *et al.*, 2018). EBM facilitated by a BH approach in small-scale fisheries may serve to redress some of the increasingly entrenched injustices of our current fisheries management regimes. Efforts to keep regulation of small-scale fisheries to a minimum and maintain their open access nature is likely to be crucial to maintaining and enhancing social equity in access to resources and allowing these resources to continue to act as a 'safety-valve' or 'social security system' for those living in socially, environmentally and economically changing and challenging systems (Kolding & van Zwieten, 2011). The use of fine mesh nets such as MNs could by no means play a small part in this, particularly coupled with the potentially large social and nutritional benefits.

2.8. Utilising this framework: addressing unilateral policies using socio-ecological systems (SES) thinking

The One Health concept is "an approach to designing and implementing programmes, policies, legislation and research in which multiple sectors communicate and work together to achieve better

public health outcomes" (WHO, 2017a). This movement takes in to account the close linkages between human health and environmental change, promoting collaborative and holistic health interventions and has been widely endorsed by national and international organisations (One Health Global Network, 2017). Whilst the initial foci of One Health were the more direct and tangible links to spread of zoonoses, food safety and antibiotic resistance, there is an increasing appreciation for its relevance to overall human mental and physical wellbeing and the relevant values of ecosystems (Clark & Lovell, 2014; World Health Organization, Convention on Biological Diversity (Organization) & United Nations Environment Programme, 2015). The arguments for the economic benefit, alongside increased efficacy of a One Health approach have also been made (The World Bank, 2008).

Despite the prominence of these approaches, the current efforts endorsed by the WHO towards elimination of malaria have been criticised for a singularity in focus, namely on distribution of MNs, and a reliance on centralised policies rather than decentralised and locally appropriate management (Killeen *et al.*, 2017b). In recent years this high dependence on the MN intervention has been highlighted further by both the rise of Pyrethroid resistance (Ranson & Lissenden, 2016), changes in mosquito behaviour (Thomsen *et al.*, 2017), and the recent reversal of global malaria declines (WHO, 2017b). Ultimately, these policies show a pervasive disregard for the new ideas posited within the One Health movement, which is perhaps unsurprising as adoption in to policies in general has been slow (Galaz *et al.*, 2014). Whilst the MNF issue is just one more incentive to give pause and review the efficacy of concentrating on MN distribution as a predominate policy, it also serves to highlight the dearth of cross-sectoral engagement on this work, with fisheries and health policy currently developed and adopted in a partisan manner.

The author of a meta-analysis of data linking numerous metrics of poverty with malaria rates strongly advocates for a balanced approach of direct (LLINs, residual spraying, treatment) and indirect (poverty alleviation) interventions to tackle malaria and argues that countries which have successfully eradicated the disease often did so by finding the right balance of these (Tusting *et al.*, 2013). Similarly, in their explorations of 'misuse' using game theory, Honjo et al., (2013) and Honjo and Satake, (2014) suggest the need to consider individual decision-making and the effects of poverty levels on decisions to fish with MNs, endorsing a focus on overall wellbeing as key to successful interventions. This of course requires tackling resource use in the vulnerable communities where dependence on natural resources is high. A number of studies have explicitly made this link before; e.g. Pattanayak et al., (2006) explore the need for interrelated economic, ecological and epidemiological studies in w hat they refer to as the "nexus of malaria, deforestation, and economic development". Further complicated by the effect of deforestation increasing vector populations, the authors explore the changes in human

behaviour and economic drivers of deforestation that serve to drive a cyclical pattern of increasing malaria, decreasing livelihoods and increasing deforestation.

These links between aspects of human wellbeing, resilience and the environment are not new in conservation and development narratives; a substantial and expanding body of research on coupled social ecological systems (SESs) has discussed these important links for some time in a recent paradigm shift away from exclusionary conservation ("nature despite people"), towards a holistic "people and nature" approach, recognising humans as part of ecosystems and all the mutualisms that involves (Mace, 2014). Practically, this has meant looking at models of social (economic, cultural etc) and ecological processes together, and has driven a great increase in the application of social sciences within conservation in order to inform these models. SES theories link very closely with resilience thinking (Folke, 2006) and the appreciation of dynamism within these systems, both naturally and due to human-induced environmental and social change and has allowed application of these theories to policy, including in development of the Sustainable Development Goals. SES approaches naturally take in to account the sorts of feedbacks explored here, between human wellbeing (particularly health and food security), natural resources (such as fisheries) and the biodiversity and ecological processes underpinning them. They also naturally engage across sectors and promote interdisciplinary work to achieve mutual goals (Leenhardt *et al.*, 2017), such as is clearly needed in the case of MNF. Such collaborations have already produced numerous operational guidelines and research goals for understanding SESs for management (e.g. Biggs et al., 2012; Kittinger et al., 2013; Levin et al., 2015).

The SES movement has been a key driver of the development of EBM and a better understanding of how these work in marine and freshwater environments is pivotal in operationalising this relatively new approach to fisheries management (Berkes, 2001; Levin *et al.*, 2015). For example, in establishing optimal yield there is an obvious need to understand the population dynamics of species under fishing pressure, and such as been the focus for many years. However, determinants of how fisheries yields lend maximum benefits socially, economically *and* ecologically also depend on a suite of management-relevant aspects such as local and global markets, societal preferences, access and equity, and environmental and social change keeping these elements in flux (Levin *et al.*, 2015; Voss *et al.*, 2014). Management efforts also need ways of assessing, where possible mitigating, and where more complicated accounting for trade-offs across these aspects and the multiple stakeholders involved (Daw *et al.*, 2015), all of which are beginning to be more holistically addressed using SES. SES thinking is particularly important in management of small-scale fisheries where society and aquatic resources are so intricately intertwined and where the need to better inform co-management efforts may be becoming the norm. In their efforts to push forward application of SES principles to small-scale fisheries Kittinger et al., (2013) describe three research 'frontiers' all of which have strong relevance

to MNF: accounting for external drivers of change including policies which may affect human behaviour (such as distribution of mosquito nets); understanding and predicting social-ecological traps when feedbacks between the systems (such as the poverty traps we describe earlier) lead to cycles that are difficult to break; and development of diagnostic approaches which illuminate multiple potential outcomes of, for example, community-based interventions; identifying which key factors influence each outcome.

The similarities in SES and One Health thinking have been logically linked in recent years with a number of studies suggesting that lessons from SES can be drawn upon to aid the development of One Health approaches. MNF provides a perfect example of where this approach is most needed. One thing which is routinely stressed in SES literature is the need for empirical and modelling studies conducted at relevant scales with which to tailor specific interventions at the local level and inform the flexibilities built in to more overarching policies (Forrester *et al.*, 2014; Kittinger *et al.*, 2013; Leslie *et al.*, 2015; Levin *et al.*, 2015). This thesis will present the first in-depth empirical case study of MNF of its kind and provide the building blocks for development of more empirical and modelling studies. Additionally there is a need for an SES approach to policy development for MNF in a concerted effort away from unilateral, one-size-fits-all policies such as blanket bans on MNF and MN distribution in anti-malarial efforts which is currently lacking in even an initial conversation amongst relevant sectors. In the next chapter I will explore the potential for cross-sectoral policy development inclusive of the relevant actors in this SES framework, drawing heavily upon the synthesis presented here to address current and potential policy responses from all relevant angles and at all relevant levels of governance. The ensuing chapters will then explore the model as it applies to the case study location in Mozambique (Section 1.4), focusing on the feedbacks associated with the sustainability of MNF within a coastal, mixed artisanal fishery (ecological drivers and processes) alongside the potential for creation of poverty traps by elucidating the role MNF plays in local livelihoods (socio-economic drivers and processes).

3. Achieving net benefits

Road mapping cross-sectoral policy development in response to mosquito net fishing

3.1. Introduction: the need for cross-sectoral policy development

The complex and far reaching potential impacts of MNF straddle issues of food & livelihoods security, biodiversity conservation, and public health, cutting across many targets within the United Nation's Sustainable Development Goals (SDGs; Table 3.1). Effective responses to the issue need to bring together the variety of sectoral bodies charged with delivering on these targets. The drivers of MNF are multifactorial; encompassing those of poverty, sustainable and equitable access to resources, and human conflict. Policy and legislation responses are justifiably required from multiple sectors concerned with public health, environmental protection, development and natural resource management.

A global public good – but who is responsible?

MNs are considered a vital public health intervention, so much so that access to their protection can be viewed as a right and therefore MNs as a public good (Guyatt *et al.*, 2002). However, where does the responsibility lie when considering mitigation of unintended consequences of their mass distribution, such as fishing? Currently there is no legal responsibility for distribution programmes to ensure correct use of MNs, and clarity on the actual risks to both food security and biodiversity is urgently needed. However, morally an obligation arguably exists for both distributors and end users to ensure that nets distributed for malaria prevention are used for their intended purpose, and disposed of responsibly once finished with.

Some urgency is necessary to resolve these obligations as globally net distribution programmes continue to expand as well as introducing new, 'next generation' nets. These nets are designed to address the increasing resistance of mosquitoes to Pyrethroids and instead employ Chlorfenapyr or Pyriproxifen insecticides for impregnation (Ngufor *et al.*, 2016; N'Guessan *et al.*, 2016). These are more likely to be a risk to humans, with the former considered highly toxic, and there will need to be strong reassurances that risks of potential entry to human food chains, due to nets being used for fishing and drying fish, have been assessed and addressed. A similarly recent WHO-endorsed promotion of Piperonyl Butoxide, which is combined with Pyrethroids to increase their efficacy, may also increase concerns over harm to wildlife (National Pesticide Information Centre, 2000; Protopopoff *et al.*, 2018).

Therefore, there is a need to ensure that any shift to new ways of treating nets goes along with strong policies and responsibilities for safe disposal.

The control of harmful fishing practices is justifiably the remit of national fisheries ministries. Currently, national policies towards MNF largely focus on enforcement of gear bans under mesh-size regulations (or sometimes MNF-specific legislation) which may be harmful to particularly vulnerable groups. Enforcement of fisheries laws in the regions of concern is often severely limited by a lack of capacity and funding (Agnew *et al.*, 2009). In reality much of the enforcement of small-scale fisheries in these regions is facilitated by NGOs, community fishing councils, Beach Management Units (BMUs) and the like through co-management efforts. As an issue of social (and particularly gender) equity (Chapter 2) which can fail to be effectively addressed by co-management schemes (Diamond, Squillante & Hale, 2003), this form of governance would be an unlikely silver bullet, particularly if we assume that MNF is an activity of 'last resort' (Chapter 2). Additionally, when dealing with the particularly vulnerable, those enacting these governance systems from within their own communities may be the most conflicted in use of these methods, further compromising the scope of effective enforcement. The common use of gear confiscations and burning (including ceremonial), the scale of which can be large and should not be underestimated (Geoffrey Furber, Ripple Africa, pers. comms), conflicts with the goals and messaging of MN distribution efforts.

The efficacy of ban policies against the use of MNs for fishing has not been assessed at a local scale or otherwise and it is difficult to determine if or where enforcement may be active. The scale of the problem at a local level (e.g. Darkey & Turatsinze, (2014), Bush *et al.*, (2016) and Larsen *et al.*, (2018)) would certainly suggest that enforcement of MNF bans in many countries by actors external to the community would be prohibitively expensive for already poorly resourced ministries. Vulnerable groups of people fishing close to the shore are more visible and possibly less confrontational. Inappropriate evaluation indicators such as the rate these individuals are arrested may mask the ineffectiveness of MNF bans whilst also having little positive impact on fishery sustainability.

Additionally, the strict differentiation of responsibility between sectors is largely unhelpful, and means that complex, cross-sectoral issues can fall through the cracks. There is a need to engage more across relevant sectors and expertise to adopt policies which address the underlying drivers of illegal extractive activities while also addressing health, poverty reduction and biodiversity conservation goals. MNF is a prime example of why this is important.

Table 3.1 - International agreements and associated targets for which mosquito net fishing is of particular relevance.

Convention/ agreement	Goal	Specific target	Mosquito Net Fishing relevance
Convention on Biological Diversity (CBD) – Aichi Targets	Target 6	By 2020, all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.	- Mosquito Net Fishing (MNF) undermines current fisheries management efforts - MNF may be conducted in fragile and vulnerable ecosystems, causing damage from the gear and trampling - MNF may cause damage beyond targeted fisheries resources to other invertebrate stocks because of its small mesh size - MNF may be encouraging new entrants to fisheries, increasing overall pressure on resources
	Target 10	By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, to maintain their integrity and functioning.	- MNF may cause damage to seagrass beds and coral reef ecosystems through physical damage and overfishing
Sustainable Development Goals (SDGs)	Goal 2 - End hunger, achieve food security and improved nutrition and promote	2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round.	- MNF may undermine small-scale fisheries (those which utilise coastal or freshwater resources for subsistence, recreation, or artisanal fishing, typically with dispersed local ownership) of particular importance to poor and vulnerable people - MNF may provide unique access to fisheries for poor and vulnerable people who may otherwise be excluded
		2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children	- MNF may compromise fisheries management efforts in areas where adjacent communities are heavily reliant on fish for food security - At least in the short term people may be heavily reliant on MNF for provision of fish

	sustainable agriculture	under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons	- The provision of small-bodied fish, particularly those eaten whole, are increasingly appreciated as key for provision of critical micronutrients of particular relevance to childhood nutrition and development
	Goal 3 - Ensure healthy lives and promote well-being for all at all ages	3.3 By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases	- MNF may be reducing bed coverage rates and therefore decreasing efficacy of anti-malarial efforts - Reduced coverage rates, even at low levels, may reduce the 'mass effect' on mosquito populations and wider malaria rates
		3.8 Achieve universal health coverage, including financial risk protection, access to quality essential health-care services and access to safe, effective, quality and affordable essential medicines and vaccines for all	- The commodification of MNs for a purpose other than protection from mosquitoes may serve to restrict access for the most vulnerable and/or incentivise alternative uses of MNs - MNF may have a bearing on the 'universal coverage' goal for MNs for people in at risk areas set by the World Health Organisation
	Goal 5 - Achieve gender equality and empower all women and girls	5.A Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance and natural resources, in accordance with national laws	- MNF may remove physical and cultural barriers to women entering fisheries - MNF may significantly contribute to ability for women to engage in savings schemes - The co-operative approach largely necessary to engage in MNF may encourage formation of informal co-operatives for women
	Goal 14 - Conserve and sustainably use the oceans, seas and marine resources for sustainable development	14.4 By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics	- MNF may undermine current fisheries management efforts, though actual impacts are unknown - MNF is broadly illegal, consequently catches and prevalence go unreported and are not incorporated in to scientific assessments - MNF largely occurs in small-scale fisheries where localised co-management (the sharing of power and responsibility between the government and local resource users) is often the endorsed mode of management – the socio-economic complications of MNF make enforcement of bans difficult in these scenarios
		14.7 By 2030, increase the economic benefits to Small Island developing States and least developed	- Current evidence of MNF occurs almost exclusively in LDCs - In the short term at least MNF has economic benefits to fishers in LDCs

		countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism	
		14.B Provide access for small-scale artisanal fishers to marine resources and markets	- MNF may provide access to previously un-utilised marine resources (juvenile and small-bodied fish) - The characteristics of MNF and availability of nets means fisheries resources may be made accessible to a broader range of user groups - The storage and transport potential of small-bodied fish may allow access to additional, increasingly distant markets for fishers
Copenhagen Consensus Post 2015 – Smart Development Goals	People	Lower chronic child malnutrition by 40%.	- These recommendations focus on dietary supplements, however, the role of naturally available sources warrants attention for increased access to nutrients independent of AID - Fish are increasingly deemed to be of critical importance to global nutrition development - Small-bodied fish provide significant contributions of protein and important micronutrients and are best targeted with small-mesh gears such as MNs - Women often conduct MNF. Female provisioning in some scenarios can provide more and better quality nutrition for children than reliance on just male provisioning (with subsequent positive impacts on overall development)
		Halve malaria infection.	- MNs are a critical tool in the prevention of malaria - The extent of alternative use of MNs is unknown, but MNF may be an important driver of trade-offs.
	Planet	Halve coral reef loss.	- MNF may threaten coral reefs due to physical damage and ecosystem effects of overfishing
	Prosperity	Improve gender equality in ownership, business and politics.	- MNF can be a significant leg-up for women in communities where they may otherwise be excluded from economic development opportunities

Current policies are conflicting or failing

High-level policies from both the health and environmental management perspectives either give little consideration to the impacts of the prevalence of MNF, or do not holistically tackle its impacts to fishing communities. The predominant response to the rise of mosquito net fishing has been that of fisheries ministries to legislate against the activity, either utilising existing fisheries restrictions on mesh sizes or to introduce novel legislation specifically for this gear e.g. Mozambique where MNF offenses now carry a potential 3-5 year prison sentence. By criminalising the activity you inherently exclude it from management and make it harder to measure and control (Adger, 2006), relying on strong enforcement to make this policy effective. In the case of mosquito net fishing enforcing against inshore, visible fishers (with brightly coloured nets) who, in the case of some marginalised users, may be less likely to question the enforcement or flee can be an easy way of making it look like enforcement is effective; i.e. facilitate a healthy arrest rate.

Significant jail sentences are likely to negatively impact the most vulnerable users and be ineffective deterrents if this is a fishery of last resort. These impacts are of particular concern in the case of female users who may therefore be disproportionately targeted. This policy of enforcement is also in direct conflict with efforts to prevent malaria if potentially useful nets are burned or confiscated, which is unlikely to be politically sustainable. There is a real danger for mosquito nets to become a scapegoat for the wider problems of overexploited fisheries. Whilst this certainly doesn't refute a role of MNF in declining catches, targeting a single unsubstantiated issue would be detrimental to overall management. The potential socio-economic issues arising from this targeted enforcement may be great and anecdotal reports are of MN fishers left in desperate states. The risk of forcing people in to more damaging activities, such as dynamite or cyanide fishing which proliferates in areas of severe desperation should be considered.

Goals of universal coverage (UC, Chapter 2) and the methods employed to achieve UC do little to limit the presence of excess nets in distribution areas (Bhatt *et al.*, 2015b) or to address the choices people make as to whether to use a net on their bed or for fishing (Honjo & Satake, 2014); something we need to understand much better. Aiming for universal coverage may be seen as a pragmatic approach to achieving levels of coverage that drive a 'mass effect' on mosquitoes, whereby mortality rates from insecticide contact may have a population-level effect and improve the effective protective range of nets (Howard *et al.*, 2000). However, increasingly effective methods are being developed that optimise delivery modes and numbers thereby making distribution efforts more cost-effective and potentially limit net availability for alternative use (Killeen & Smith, 2007). Opportunities exist both to understand the dynamics and drivers of MNF and to adapt current policy to avoid negative socio-economic and

ecological impacts, and to bridge sectoral gaps to develop synergistic policies that can have broader benefits.

Feedbacks inextricably link sectoral impacts; expert objectives align

Potentially the strongest illustration of the need for cross-sectoral collaboration in mitigating MNF is the complexity of the potential feedbacks of the activity highlighted by the conceptual framework (Figure 2.6), rooted as it is within health, economic, cultural and ecological aspects of the communities where it occurs. The interlinking goals of maintaining food security, improving access to healthcare, reducing poverty and maintaining ecosystem services across all of the sectors mentioned here highlight the fact that, actually, the objectives of these sectors concerning MNF are firmly aligned. Yet there has been no recognition of this in policy. To begin to address this, this chapter aims to draw on expertise across sectors and disciplines relevant to MNF to explore the synergies and conflicts of current and future policy options. The chapter is the product of a two-day collaborative workshop led by myself and researchers from the Interdisciplinary Centre for Conservation Science, Oxford University, at the Oxford Martin School, UK in November 2017. Cross-sectoral representatives from industry, NGOs, science and policy with a broad suite of fisheries, conservation, public health (including specifically malaria focused) and development expertise were invited to participate in a first-of-its-kind discussion about policy development specifically for MNF, from global to local scales.

3.2. Methods

A two-day workshop was held at the Oxford Martin School on 31st Oct – 1st Nov 2017. The workshop employed a mixture of expert knowledge elicitation methods. Invited experts (Table 3.2) were either segregated for intra-sectoral discussions with subsequent contribution to plenary discussions, or randomly mixed in to representative cross-sectoral groups for both brainstorming and refinement activities. A core aim of the workshop was to consult these experts to elicit key policy arenas in which the MNF issue could and should be addressed. This discussion centred on the individual decision-maker, appreciating that the choice to use a MN for malaria prevention or for fishing is affected by both push and pull influences, whereby individuals may be both attracted and forced in to fishing and that both are impacted by current policies.

Table 3.2 - List of organisation representation in attendance at the workshop and their sectoral affiliation

Sector	Representation
Biodiversity conservation	Interdisciplinary Centre for Conservation Science, University of Oxford, UK Zoological Society of London, UK Imperial College London, UK Blue Ventures, UK Wildlife Conservation Society, Indonesia Worldwide Fund For Nature (WWF UK)
Malaria	VectorWorks, Johns Hopkins University, USA Lake Tanganyika Floating Heath Clinic, USA London School of Hygiene and Tropical Medicine, UK Vestergaard Frandsen, Switzerland Independent consultant, UK
Fisheries mgmt. & Development	Interdisciplinary Centre for Conservation Science, University of Oxford, UK Northumbria University, UK Stockholm Resilience Centre, Sweden Syracuse University, USA MRAG fisheries consultancy, UK CORDIO East Africa, Kenya

The structure of the workshop was designed over several iterations of 'workshopping the workshop' with the ICCS team to enable an open and solutions-focused discussion. This structure allowed free flowing conversation, open opinions and new ideas, whilst drawing on aspects of structured decision making (SDM) alongside advice on effective planning for expert knowledge elicitation from Martin *et al.*, (2012). SDM is increasingly used to lend a structure to expert but subjective judgement and enable the addition of empirical data to later models in environmental decision making processes (Addison *et al.*, 2013). Whilst SDM is more often employed in scenarios where full consensus is required, e.g. investment in climate adaptation strategies (Wintle *et al.*, 2011), these methods were adapted to the need for an exploratory process for MNF, facilitating constructive and practical outputs which explicitly recognise conflicts, uncertainties and variable priorities (Appendix A.2). To achieve this, the workshop operated under the Chatham House Rule (Chatham House, n.d.), whereby attendees were free to use the information discussed in the workshop, but the ultimate source of any information or views could not be identified.

As a poorly understood issue, the workshop focused on a three-stage discussion around: a) defining the problem and what we know and do not know; b) determining appropriate avenues for policy development going forward; and c) reviewing existing or novel interventions that may contribute to these recommendations. An iterative process of follow-up consultation with workshop attendees following the event was complimented by a literature review of supporting research performed by myself, including engagement of further expertise where necessary, in order to formulate the final exploration of policy options and recommendations for future development in which uncertainties are explicitly acknowledged and group consensus reached.

The full workshop agenda and facilitation plan is included in Appendix A.2.

Selection of participants

Participants were invited based on several years of networking and discussions, which largely relied on snowball sampling and the results of an extensive prior literature review, conducted by myself. Prior to formal recruitment, a breakdown of necessary expertise and organisational representation was drafted to ensure best possible balance. Financial barriers to participation from, for example, NGO representatives were removed thanks to kind support from the Oxford Martin School, Imperial College London and the Zoological Society of London.

Participants were provided with a brief background document prior to the workshop in accessible language, which aimed to provide basic context and enable a minimum knowledge-level for all participants across relevant sectors. A recommended reading list of key literature was also provided. Prompts were provided throughout the workshop alongside guiding questions to ensure activities were performed and questions were addressed according the pre-planned structure, but building in flexibility given the nature of the subject. For breakout sessions, each group was designated a facilitator who was provided with detailed instructions. All plenary sessions were formally facilitated by Dr. Prue Addison of ICCS.

Defining policy needs; identification of drivers and impacts

Attendees were split into sectoral groupings as per their expertise: Conservation, fisheries and development, health. Groups then independently brainstormed the questions below, with a prompt to think about extent, geographic spread, timescale, severity and their confidence in their assessments. Groups then reconvened in plenary in order to discuss and categorise the outputs.

- *What positive and/or negative consequences do your sectoral group feel may be attributed to MNF?*

- *What do you perceive are the likely drivers of the decision for a person to use a mosquito net for fishing?*

  NB – this decision context implies that anyone owning a net knows what its intended purpose is and the consequences of not using it on their bed; this may not always be the case so please allow for this in your thinking.

Cross-sectoral objective setting

Attendees were again split into sectoral groups in order to brainstorm some potential objectives for MNF, in order to guide future research and decision-making (ultimately policy development). Whilst the groups sought an ultimate 'end' objective, they were also encouraged to focus on key 'means' objectives which would facilitate it, and whether objectives were long or short term. Groups could be selfish as to their own sector's goals.

- *What do you, as a group, ultimately want with respect to MNF? What would an ultimate goal/change for the future look like?*

The workshop attendees re-convened in plenary to discuss each group's objectives and honed down a final set of key objectives, removing any overlaps/redundancy.

Identification of synergies and conflicts

Attendees were randomly mixed so that all sectors were represented in each of four groups. The objectives set previously were then re-discussed in light of the mixed perspectives:

- C*an we have all of these objectives?*

Participants were asked to group objectives which may complement one another, and identify any hindrances or conflicts between objectives for further discussion.

Operationalisation and feasibility

In this creative session, groups were once again randomly mixed with representatives of each sector in each group, and asked to come up with as many existing, adaptable and/or novel potential interventions for management of MNF. Groups were also encouraged to think about which existing policy avenues each intervention might be relevant to.

- *What specific interventions exist (or are thought of now) which may be implemented or adapted to achieve the set objectives? What are the policy mechanisms by which they could be employed?*

These interventions were then grouped in plenary as per the policy mechanisms they were most relevant to, with the addition of a grouping for 'translation to governance', which were actions that

could be taken to better incorporate the issue of MNF into governance at a variety of scales. Attendees self-nominated themselves to a policy group in an area of interest and the groups split-off to conduct feasibility assessments for interventions using framework of critiquing criteria (Figure 3.1).

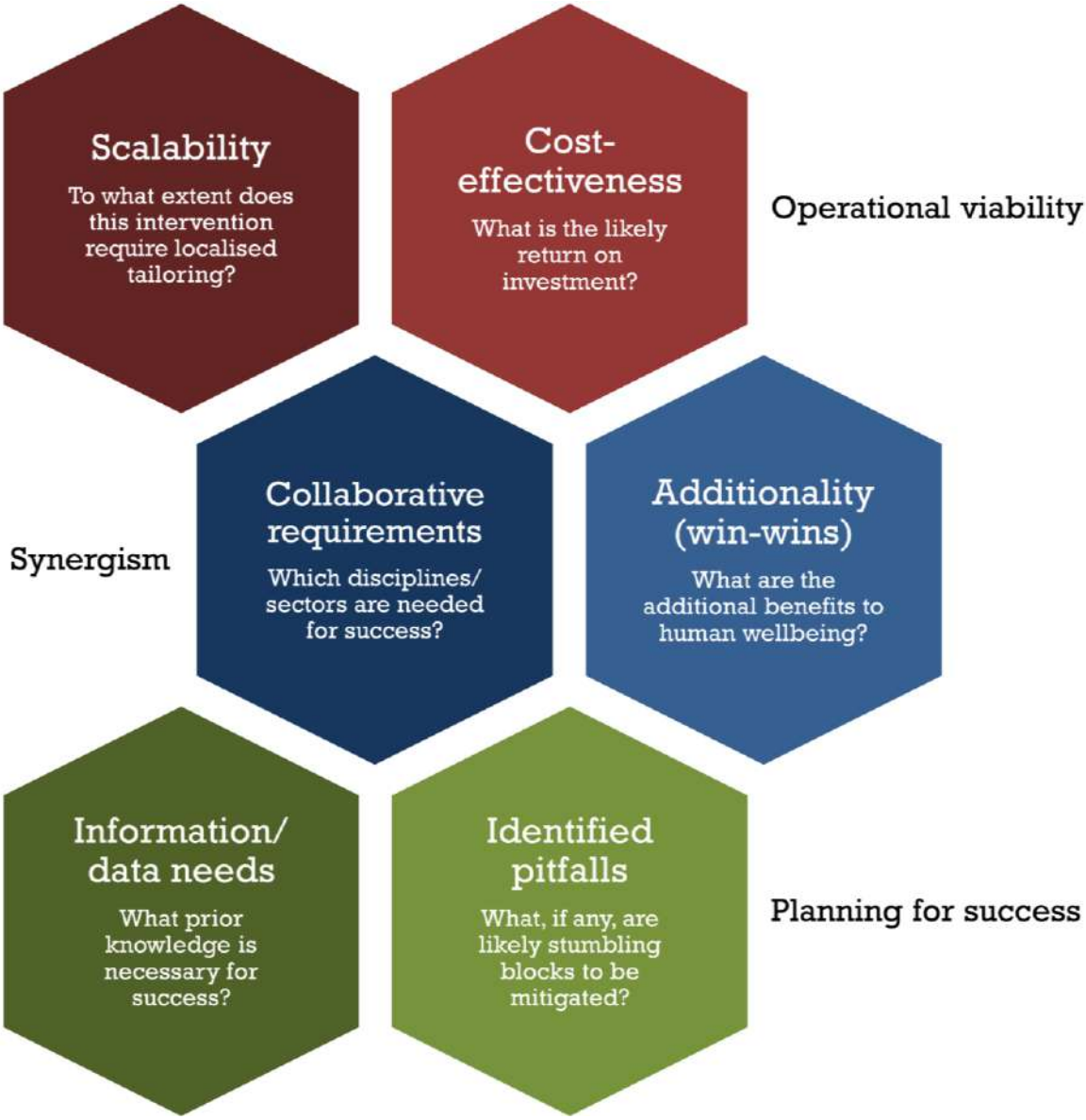


Figure 3.1 - Basic assessment framework for mosquito net fishing interventions.

3.3. Objective setting

The initial task of the 2017 workshop was to address the synergistic and antagonistic aspects of the complicated set of feedbacks associated with MNF. Following structured discussions, the group proposed the following cross-sectoral objectives to guide both the development of the recommendations and to engage policy makers across sectors toward some common goals:

- Main aim: Healthy people exist in a healthy environment where nobody in water-based communities dies from malaria and sustainable fisheries are supporting ecosystem function and meeting nutritional needs.
    - Improved understanding of the drivers and impacts of MNF, as well as identification of Key Affected Areas (KAAs) are incorporated in to current management objectives across sectors, with its priority increased.
    - Policy is geared towards removing the want/need for MNF and moves away from reliance on post-hoc enforcement policies.
    - Policy-making is evidence-based and data collection is collaborative and inclusive at the local level.
    - Tailored vector control is accepted as a policy and cost-effective assessment methods developed.
    - Implementation of interventions is participatory and collaborative at the local level.
    - Gender equity is incorporated in to MNF-focused policy and effectively promoted where MNF issues exist.
    - Equity and procedural justice is core to delivery of interventions, with these ideals reflected when incorporated in to local institutions and governance.
    - Ecosystem-based management underpins natural resource use with a goal of resilient socio-ecological systems.
    - The commercialisation and commodification of MNF is avoided, including top-down regulation of external markets where necessary.

3.4. Interdisciplinary identification of policy avenues

Four key avenues were identified through workshop discussions (Figure 3.2) and subsequent iterative grouping of individual interventions by theme, and some examples of specific interventions are given below. Table 3.3 contains a thorough analysis of key interventions relevant to the policies that were discussed:

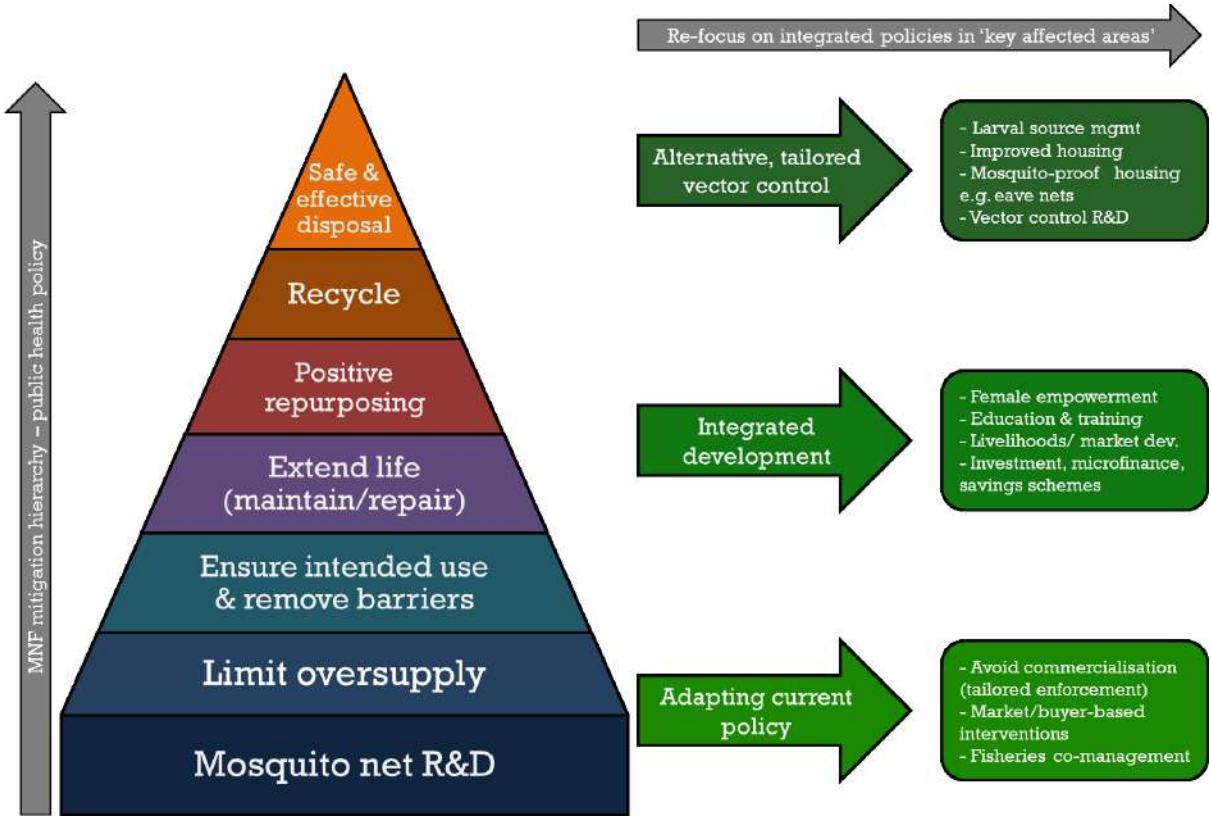


Figure 3.2. Proposed mitigation hierarchy and parallel, cross-sectoral policies for addressing mosquito net fishing in malarial zones.

Reduce, repurpose, recycle: the mitigation hierarchy

The ready availability of both new and used nets has been posited as a significant incentive for MNF (Bush *et al.*, 2016). The current WHO policy sets guidelines at a broad population level of 1 net for every 1.8 people to achieve UC. This is designed to necessarily optimise net distribution for practical reasons of resource availability, and unfortunately these targets are still hampered by such limitations, with studies showing that the predominant limiting factor for coverage remains net availability (Koenker, Ricotta & Olapeju, 2018). However, it has been argued that the level at which these recommendations are set may oversimplify optimisation and lead to over- (and indeed under-) supply at local levels (Bhatt *et al.*, 2015b). Moving away from global, blanket guidelines, modelled and empirical studies could aid understanding and optimisation of vector control efforts better at a local scale. Methods already used to understand the mass effect and environmental and social characteristics impacting local epidemiology could be employed at these finer scales to improve efficiency and minimise oversupply (not by reducing nets delivered, but by delivering them to the appropriate households) whilst also optimising the 'mass effect' (Killeen & Smith, 2007; Hawley *et al.*, 2003; Bhatt *et al.*, 2015b; Dlamini *et al.*, 2017). Further development of such methods could constitute a potential win-win for those addressing MNF and for coverage targets.

The 'public good' argument for access to nets by all is a strong one, however this argument is better posited as a right to protection from malaria vectors, rather than a right to a mosquito net specifically. Other vector control methods can be considered under this argument and yet remain underutilised and underdeveloped (Killeen *et al.*, 2017a), for example, coating the walls and other surfaces of a house with a residual insecticide (Indoor Residual Spraying; IRS) or use of grassroots larval source management methods which reduce potential breeding grounds for mosquitos. For those nets which are distributed, a key objective should be to ensure that practice is geared towards maximising intended use, firstly by removal of physical, social and educational barriers to hanging the nets over beds (inclusive of research and development for new net designs). There is significant evidence of a positive effect on bed coverage of removing barriers to use (Pulford *et al.*, 2011). Highlighting the potential long-term and negative impacts of MNF and promoting sustainable and equitable fisheries use to target communities should also be encouraged. Integrated education, social marketing and behaviour change programmes may be applied to this goal.

Delineating nets as either 'new' (fit-for-purpose), 'end of life' (no longer fit-for-purpose), or 'unserviceable' (in need of disposal) is necessary for management and has important policy implications. The influence of MN condition may be best viewed on a spectrum of policy interventions as part of a 'mitigation hierarchy', where end users may first be actively encouraged to repair nets for continued use on beds (a recommendation already supported by WHO). Once nets are deemed beyond repair for use on beds, they may be repurposed for a number of beneficial vector control uses such as window screening or covering water sources to prevent use for mosquito larvae. These policies will require appropriate and clear communications on care and repair and categories of beneficial repurposing for success. The Alliance for Malaria Prevention has already drafted key repurposing recommendations that should be promptly reviewed and adopted.

Finally, the nets should be safely disposed of. Advice from the WHO on disposal of nets post-use is currently limited to recommendations for safe disposal via incineration (WHO Global Malaria Programme, 2014) – a policy which does not account for shortages of waste collection and incineration facilities in many affected countries. Overall, WHO discourages collection of MNs for disposal or recycling unless the potential risks to the universal coverage goal are mitigated, about which there is no clear advice (WHO Global Malaria Programme, 2014). I would argue that this may have perverse impacts in KAAs, beyond the consequent availability of nets for fishing; retaining nets beyond their useful life can impact insecticide resistance in mosquitoes (Norris *et al.*, 2015), and with an urgent need to tackle plastic pollution globally, to have no disposal policy for 1.4 billion plastic nets is negligent. Recycling of MNs is a valid policy option when coupled with development of a collection model that can both relieve strain on waste disposal systems and identify gaps in coverage through needs

assessment. Collection models need to consider locally appropriate incentives. Where this recycling is not possible, better policy on safe disposal needs to be developed.

Alternative vector control

The distribution of MNs is currently the largest malaria prevention intervention employed in developing nations, both in terms of investment and operational scale (Bhatt *et al.*, 2015a). However, numerous other interventions exist at various levels of development, deployment and mainstreaming which may be considered underutilised in a policy and funding environment that favours MN distribution. MNs have resonated strongly with the public and generate significant funding, both direct (personal donations) and indirect (national taxpayer contributions to the Global Fund), thanks to the tangible nature of 'give a net, save a life' marketing. Whilst this has advanced the capabilities of international efforts and National Malaria Control Programmes (NMCPs) to deliver nets, it has arguably neglected the deployment and therefore development of alternative methods. Indeed, in developed nations success in malaria control has mainly been achieved through mosquito-proof housing and environmental management (Killeen *et al.*, 2017b). A unilateral reliance on WHO-endorsed products by many countries has stifled innovation in both the development of new MNs and alternative vector control tools due to prohibitively long and bureaucratic approval processes, which can be seen to perversely inhibit the private sector from advancing the fight against malaria. As malaria rates have begun to increase, it is increasingly realised that the reliance on a single tool in the collective toolbox for fighting this complicated disease is ineffective and potentially even harmful to overall efforts.

There is an opportunity, and a renewed appetite, to diversify vector control interventions away from reliance on MNs (Killeen *et al.*, 2017a, 2017b). This diversification could be particularly effective in tackling issues such as MNF, alongside issues of insecticide resistance and intervention fatigue. Whilst a goal of universal coverage of health interventions for at risk populations remains key, the goal of universal coverage of MNs may become less so as other interventions become mainstream. Indoor Residual Spraying (IRS), already broadly deployed in regions of high risk, has been hampered in up-scaling by historical issues of DDT use and negative publicity for insecticides more generally (Hlongwana *et al.*, 2013; Sadasivaiah, Tozan & Breman, 2007). Methods are being developed for more appropriate mosquito-proofing of households in developing settings e.g. eave tubes (Knols *et al.*, 2016). Grass roots innovations in larval source management may alleviate environmental concerns over a focus on larvicide use and legitimise this further as a viable broad-scale intervention. At the level of household/individual protection, insecticide-treated clothing may protect people both inside and outside their homes (Killeen *et al.*, 2017b). For a comprehensive review of current, re-purposed and developing tools in the toolbox refer to Killeen et al., 2017; 'Developing an expanded vector control toolbox for malaria elimination'. A key direction for this diversification may be to focus on cross-

sectoral collaborative approaches to improving housing quality for mosquito protection, with all of the associated health, development and security benefits this would also bring.

An integrated livelihoods & development approach

Global policies on fisheries management increasingly seek to marry food security and ecological objectives towards sustainability under the umbrella of ecosystem-based management (EBM). EBM seeks to incorporate the connections between economic, food security, cultural and wellbeing contributions from fisheries in to management in a more holistic effort which also aims to protect biodiversity as a whole over single stock foci (Bianchi & Skjoldal, 2008). Renewed efforts through the EBM movement would therefore also seek to diversify management strategies from a singular focus on effort and gear-based methods towards adaptive, stakeholder-driven methods that employ a full toolbox of appropriate spatial, temporal, technological and rights-based tools. In cases such as MNF where poverty drivers are acute, development and livelihood-enhancement options are potentially more effective. Similarly, fisheries and health ministries may do well to adopt policies which complement each other's' objectives on this issue, combine and enhance data gathering to avoid duplication of effort and develop mutually beneficial policies which enable localised tailoring of interventions.

When it comes to drivers, and therefore interventions, MNF is primarily an issue of local livelihoods, vulnerability, food and nutrition security and secondarily one of health and environment. This does not divert the need for policy responses from health and natural resource management bodies, but does pose an opportunity for holistic responses with win-win outcomes across these sectors and others. Addressing the issues which push people into activities that they believe are illegal, damaging and ultimately unsustainable requires perspectives that are much broader than simply malaria prevention or fisheries governance. To address the root cause of MNF would require a truly interdisciplinary approach to both future research and interventions, and could potentially reap benefits much broader than reduced malaria prevalence.

To be effective, alternatives to MNF will need to address opportunity costs for both those highly dependent on its contribution to subsistence, and those who may have enhanced their individual or household wellbeing from increased food and/or incomes. Critically, these alternatives would need to address the potential for a reduction in MNF leading to decreased provision of protein and vital micronutrients, at least in the short term, as well as decreased ability of MNF households to weather seasonal or longer starvation periods. This in itself is representative of the broader need for a culture change in food security policy; an often disproportionate focus on agriculture over wild harvesting, and a disproportionate focus on protein provision over other nutritional value where fisheries are

concerned (Thilsted *et al.*, 2014). Both of these are increasingly appreciated as detrimental to the efficacy of policies promoting health and wellbeing of poor households.

MNF represents an example where broad-scale policy-making risks overlooking the importance of both small-scale aquatic food and micronutrient provision. Further research in these areas should be a priority, as should the consideration of modes of access to these resources. Any prohibitive intervention needs to have a good understanding of the trade-offs involved for both communities and individuals currently engaging in MNF, including long and short term disadvantages in terms of nutritional status. Aside from those directly benefitting in coastal areas, the potential contribution to inland nutrition by these easily dried and transportable fish would need to be much better understood if policymakers wish to avoid negative impacts from interrupting the market chain of what is potentially an important resource. Alternatives would also need to be culturally relevant and sustainable, with appropriate market development and education to maintain this in to the future, building resilience for environmental and societal change. Specific thought needs to be given to displaced peoples, migrants and those living in conflict areas that may be particularly prone to malaria, hunger and MNF. For these people, 'stop-gap' interventions may be necessary in the short term.

MNF and gender mainstreaming

Both in terms of integrating development goals into interventions, and also because of the reportedly high representation of female fishers in MNF (Gettleman, 2015) and the general lack of attention to, but growing appreciation of, the importance of women in fisheries (Harper *et al.*, 2013, 2017), it would be folly to ignore the benefits of women's self-empowerment and potential opportunities for societal benefits that MNF brings.

Investment in women can have a disproportionately positive community-wide impact and women can be more disposed to investment in the future and more likely to engage in savings schemes (Ranis, Frances & Alejandro, 2000; Porter & Mbezi, 2010). MNF may promote autonomy for women through independent access to food and income which could be considered a small step towards more equitable access and use of fisheries resources for women were this activity to be capitalised upon. These benefits should not be negated in the pursuit of effective interventions – a particularly pertinent point when considering the efficacy of bans. Secondly, the self-organisation, development of markets and general promotion of financial literacy that may be associated with activities such as MNF present an opportunity for development interventions. Where women engaging in purely agricultural activities may spend the majority of their days alone on their family plot, fishing is a sociable and necessarily co-operative activity which not only contributes to women's wellbeing, but also social and economic mobility. Investing in other strategies for maintaining these benefits, by capitalising sustainably on

MNF's contributions to gender equality and creating further opportunities for women, would probably have a huge impact on reducing the prevalence of MNF.

Adaptive management applied to current policy

Whilst we have made arguments against the sole use of current enforcement policy for MNF, we also appreciate the role it must play in addressing cases of MNF where the drivers of the activity may be less directly connected to poverty. Whilst current evidence points to MNF remaining a subsistence or artisanal activity, larger-scale activities and threats of commercialisation have also been identified, such as use of the catch from MNF in animal feed production. External actors and market drivers may have a significant impact on the scale at which MNF is conducted. Where these drivers are significant, monitoring and enforcement is likely to be necessary.

In these scenarios, which are likely to be complicated and still ultimately linked to poverty, adaptive fisheries co-management initiatives as part of EBM, recognising the role of communities and individuals and including them in development of contextually appropriate legislation and delivery of enforcement. Co-management is grounded in community participation, aiming for fully inclusive and representative development of management plans with local people. Government ministries and NGOs play a supporting role and deliver the scientific bases for these plans, with an interdisciplinary team critical to successful guidance (Berkes, 2009). It would also be prudent for malarial interventions and co-management initiatives to aim to complement one another and include goals of human wellbeing development, involving relevant expertise in this area when necessary, and combining education and behaviour change efforts to align messaging and increase impact. Additionally, market-based drivers and external influences should be addressed with appropriate mechanisms that target organisations/buyers throughout the market chain.

3.5. Sectoral recommendations: translation to governance and action

International policy makers (WHO & FAO)

From the arguments presented here it is clear that there are significant benefits to be reaped from encouraging a cross-sectoral approach to policy development for MNF, and this will ideally start from the top levels, including the United Nations. There is a need to support collaborative actions, particularly engagement of the Food and Agriculture Organisation as perhaps the most meaningful organisation in terms of fisheries management, whilst appreciating the central role that the World Health Organisation must continue to play. Specifically for MNF, the WHO and FAO should collaboratively support identification of key affected areas for MNF, both areas of current activity but also areas of risk due the dynamic nature of the issue and potential impacts of social and

environmental change. Policy should then support the role of adaptive management in addressing MNF in these areas, determining common ground, and importantly a common language, between sectors for development of a broad-scale adaptive management framework alongside promotion of context-dependent, win-win solutions.

Framework development should start with the facilitation of a one-off, cross-sectoral values-mapping process at a variety of scales. The goal of this process would be to explicitly recognise areas of agreement and difference between stakeholder sectors on the issue of MNF, building on the information within this chapter. Conducting this exercise at a range of levels from first local (utilising case studies) to international will ensure rigour in the outputs that can then be used directly to inform an adaptive management framework for a particular intervention area that accounts for issues at all levels. The establishment of a centralised database of localised information, to which all sectors may contribute, would be a pivotal tool in the delivery and communication of successes/failures in a daptive strategies and should be a priority for international policy development. The additional benefits of such a database to the devolved targets of the various sectors, both in terms of practical data provision and in terms of building a collaborative culture would be great.

A key role for international policymakers in tackling MNF will be to spearhead a culture change in policy development that enables innovation in vector control. Moving away from reliance on MNs, both in key affected areas for MNF but also for other problem areas, will require efforts to change the investment landscape and provide incentives for increased engagement of researchers, business and the private sector, both operationally for research and development but with the additional benefit of diversifying funding. Importantly, but bearing in mind the need to promote and design these adaptive management strategies in parallel, there is a need for the WHO to provide a vastly more comprehensive set of MN disposal and repurposing policies, inclusive of better environmental and human health safety standards and appreciation of national waste disposal limitations.

These recommendations align well with the strategic visions of both the WHO Global Technical Strategy for Malaria (GTSM) and the Roll Back Malaria Action and Investment to Defeat Malaria (AIM) reports (World Health Organization, World Health Organization & Global Malaria Programme, 2015; Global Partnership to Roll Back Malaria, 2015) which lay out the necessary policy developments needed in 2016-2030 to achieve current targets. Both reports commit to increased engagement across sectors in order to 'strengthen the enabling environment', policies which support an integrated development approach within which MNF should be a key consideration. The goal of ensuring enabling policy environments is mirrored in the FAO's Voluntary guidelines for securing sustainable small-scale

fisheries in the context of food security and poverty eradication, which highlights the need to better embed the sector in a wider institutional and policy context (FAO, 2015).

All three documents also contain recommendations for the advancement of gender equality and give some credence to the critical interplay between food security and health, and specifically malaria. However, the recommendations from WHO and RBM focus solely on agriculture and do not account for the huge nutritional importance of fisheries and subsequent impact on overall health and wellbeing, and therefore the role of MNF; a gap which needs to be urgently addressed. Accordingly, the FAO will play a key role in endorsing adaptive policies towards fisheries management specifically for MNF, recognising the unique feedbacks involved in MNF to avoid negative impacts of inappropriate top-down and/or blanket enforcement policies. This will require a parallel culture change and difficult conversations over challenges to the impacts of MNF, particularly where they are erroneously seen to be ubiquitous. Innovation and a more rapidly adaptive policy environment are central to the policies outlined, and information regarding MNF should be incorporated into research and development plans. Better data collection and sharing across organisations, and use of that data for evidence-based interventions and participatory action is particularly important, accounting for the difficult decisions being made by those in severe poverty.

Cross-sectoral steering groups

The facilitation of a values-mapping process would also provide an opportunity for the development of cross-sectoral steering groups to operate at international, and national levels, with key affected areas specifically addressed by regional groups (where the issue is cross-border) to provide guidance for national and local level implementation of the adaptive management framework. A key role would be to identify and engage expertise to guide delivery for interdisciplinary aspects of interventions, ensuring modes of communication between disparate groups who may not have an obvious obligation to do so under the current modes of management. Additionally, the steering groups can act as a proactive policy feedback mechanism for evaluation of the framework, direction of research and development funding as issues arise, and a conduit for information of value to public engagement efforts. At the uppermost level this group should comprise of representatives from key United Nations programmes (WHO, FAO, UNDP, UNEP), The Alliance for Malaria Prevention (AMP), international conservation and development NGOs and key academic groups with relevant expertise in natural resource management and population health evaluations. At regional and national levels it will be important to include significant operational expertise from delivery of conservation and fisheries management (e.g. co-management), MN distribution and evaluation programmes and existing integrated development programmes to formulate context-appropriate advice for implementation.

Generating funding for both an urgent values-mapping process, and the facilitation of the cross-sectoral steering groups must be a first priority.

National implementing bodies

At the national level it will be critical for government ministries responsible for fisheries management (and law enforcement), education, public health and development to begin to align policies on MNF and develop action plans which account for localised characteristics of MNF. This will require better co-operation on information gathering and incorporation of MNF-specific data needs into micro-planning (needs assessment) processes for MN distribution and other malaria interventions, such as those recommended by the Alliance for Malaria Prevention (Erskine & Rockwood, 2013). Fisheries and development bodies should be involved in MN distribution planning processes from the start to identify and assuage potential problem areas, and this should also extend to subsequent surveillance, monitoring and evaluation efforts. Importantly, local, district, provincial and national (or the equivalent) authorities need to ensure they are communicating across hierarchies to mitigate geographical inequalities in opportunity costs and the potential for conflict. This will additionally ensure traceability and accountability for MN distribution programmes, identifying issues such as net leakage and corruption in the early stages of a programme.

Consequent policy and action plan development should aim to remain collaborative. For example, behaviour change programmes can integrate messages across delivery modes such as schools, health clinics and fishing councils. Operationally, many sectors employ similar methods for deployment and evaluation of interventions, use similar modes of access and communication, and many of the messages delivered align with overarching sustainable development goals – opportunities to combine or enhance these operations to achieve multiple sectoral objectives should be sought. An additional benefit of this will be to limit duplication of effort and greatly improve the quality of information gathered. The development of multi-sectoral action groups, which are advocated for within the AIM report and have shown great success, critically need to engage with the fisheries sector wherever appropriate. National bodies should also aim to support the identification of KAAs and in the short-term feed-back information on the scale and variability of MNF to both international bodies and also academic researchers seeking to better understand the characteristics and drivers of this activity.

Non-Governmental Organisations

Engagement from NGOs is required for an effective response to MNF at local and national levels, with broad support for policies set at the international level. Public health, development and conservation-focused organisations all have a critical capacity to act as a unifying gateway to local information, governance and influence. NGOs should be engaged particularly for facilitation of dialogues at the local

level, including for neutral engagement of MN fishers themselves, needs evaluations and values-led discussions of community-led interventions. For those NGOs focussed on conservation and/or fisheries management, particularly those supporting co-management initiatives, incorporation of MNF into management and critical challenges to enforcement-centric policies when engaging with local governance would be of benefit. The diversification of vector control will critically need to be supported by malaria-focussed NGOs with appropriate donor support and alignment of goals. Accordingly, the targeting of public support and prominence of public campaigns must be adapted to new strategies. NGOs can play a crucial role in guiding evidence-based interventions, including informing academic research, and should be sought and consulted on issues of surveillance, monitoring and data collection.

Private donors and business

Donors and private business can both respond to and influence policy direction. However, this is something that has been expressed as lacking in terms of malaria interventions, particularly vector control, resulting in a paucity of investment in innovation to address emerging challenges. Donors can both direct and respond to the actions of private business, depending on the challenge they seek to meet. Under a freer investment landscape with our recommended international policy changes, responsible developments from the private sector would be at the centre of improving adaptive capacity to meet challenges such as MNF and reduce the dependence on MNs as an intervention, including through innovative funding channels that marry this sector with national implementing bodies, NGOs and research bodies. Opportunities exist for engagement and promotion of responses from a wide variety of companies, from pharmaceuticals, to tech, to communications.

Endorsement of products and strategies by the WHO will remain critical to funders. However, the promotion of a rapidly responsive policy environment would address temporal barriers and improved communications as well as the open integration of inter-disciplinarity and engagement of external expertise into future developments. This may serve to cut out some of the prohibitive barriers. For example, engaging with human development NGOs may serve to highlight a number of operational barriers to delivery and success of an intervention during development stages, allowing adaptive capacity to be worked into product design. Similarly, funders should seek to release funds for field trials of new products under varying contexts independently of direct R&D funds. Platforms and seed funding opportunities which facilitate mixing of sectors, interdisciplinary conversations and opportunities for collaboration that engage with private business and showcase needs to donors (e.g. hackathons, competitively commissioned design solutions) should be encouraged both externally (governments/UN etc.) and within private companies.

Academic research & funders

Academic research has the potential to support much of the decision-making involved in employing adaptive management policies, as well as playing a pivotal role in innovation, research and development of new vector control products. Funding and research effort should be directed towards research which seeks both to set baselines for understanding the role of MNF in socio-ecological systems in order to inform development of appropriate interventions, and to improve the collection and use of data for monitoring and evaluation of subsequent interventions employed. Priorities include understanding gender aspects of MNF (the role played and benefits accrued by women in particular), the nutritional impact of MNF across vulnerable groups and assessing MNF impacts on fisheries and benthic habitats. The promotion of interdisciplinary science and robust methods to answer these questions should be at the core of funding objectives, alongside active involvement of in-country researchers and research institutions.

Academic research has been highlighted by the GTSM as central to fostering and sharing innovations and solutions to global malaria challenges. This is particularly true for the creation of new tools and vector control strategies that may enable adaptive management policies to be employed in key MNF affected areas, with wider benefits. Academic and private sector collaborations should be fostered to advance these efforts and provide guidance to one another on specific development needs for both operational and economic viability of new solutions.

3.6. Developing implementation

In the development of adaptive strategies to MNF, and vector control generally, a critical appraisal of current and future interventions as part of a 'toolbox' is key at a range of scales, including for MN distribution itself. This should aim to identify potential contextual issues and key stumbling blocks, providing advice as to applicability, cost-effectiveness, current state of development (and therefore needs) and complementarity with other interventions. Interdisciplinary expertise should be sought for all assessments. In Table 3.3 I provide an assessment of interventions for responses to MNF challenges from a brainstorm undertaken at the interdisciplinary workshop in November 2017, drawing on cross-sectoral expertise using the assessment framework (Figure 3.1). Whilst 'Evidence of success/failure' is clearly a necessary aspect of these assessments, this is included as a given under aspects of 'Planning for success' and a more structured approach to gathering this evidence is advocated for based on the previous recommendation for the support of a centralised database, rather than encouraging ad-hoc assessments by implementation teams. This is in no way intended to be an exhaustive list, neither are interventions to be considered in isolation. Some address MNF very specifically, whilst others seek to address underlying drivers of MNF. However, it is hoped that this example of a framework may act as

clear evidence of the need and potential additionality from an interdisciplinary approach, an illustration of the feasibility of adaptive management, and a catalyst for a rapid change to the policy culture surrounding malaria vector control and MNF.

3.7. Discussion

The outputs of this workshop exceeded expectations in terms of content and depth, particularly the level of support and consensus across sectors, despite participants expecting potentially high levels of conflict. The methods were purposefully developed under the expectation of difficulty in reaching consensus across sectors, and necessarily allowed for knowledge gaps in this poorly understood topic. Ultimately most recommendations were agreed upon, and involvement and advice from other sectors in intra-sectoral issues was not merely tolerated but invited and encouraged. This is partially due to the timeliness of this research, where cross-sectoral conversations are able to build on some initial conversations being had within sectors but unfortunately with limited further communication (e.g. by Killeen *et al.*, 2017b). However, interdisciplinary work such as this is also facilitated by the unifying role of the Sustainable Development Goals. Mosquito net fishing represents what could be seen as a number of clear conflicts between SDGs. Conflicts between goals should be better acknowledged in such cases if we wish to achieve net positive gain across them, however as we have demonstrated here they may also be appreciated as opportunities for win wins and additionality by catalysing such collaboration.

The workshop process itself worked well in eliciting the relevant knowledge in a suitably formal format from attendees. Given the limited timeframe, the rigid structure that is necessitated by an SDM-type approach was well complimented by periods of free-flowing and creative input. A noted weakness of the workshop in subsequent feedback was a lack of available 'hard evidence' to apply to the process. This was indeed a limitation, but one which was explicitly and openly incorporated in to the process. Despite the dearth of evidence currently available it was broadly agreed, and I believe demonstrated, that a response or at least a correction of current responses is timely for MNF whilst concurrently promoting the critical need for filling of knowledge gaps. The workshop additionally achieved the notable impact of creating advocates for the issue across sectors. This movement is necessary for the removal of the onus for addressing MNF from where it currently sits, largely at the door of fisheries managers. The impact of this will be to promote the formation of steering groups at varying scales that reflect the expertise necessary to continue effective policy development.

The next steps for policy development are necessary, active communication of the above recommendations. Whilst it is a boon to the issue that this will in part be facilitated by the Oxford Martin School through their policy communication series of papers, it is a similar boon to have

formulated a supportive cross-sectoral network able to communicate this further. Notably missing from the representation presented here are international policy makers. These relevant organisations, the appropriate UN programmes, global funding bodies and global private industry remain the target audience for these workshop outputs and are necessarily missing from the discussion at this stage. A critical next step will be not to ensure the policy discussion for MNF begins in each of their offices, but that it happens within a single conversation that draws them together as per our conclusions here. Whilst the following chapters will re-focus on the evidence-base, addressing some of the critical needs identified, within this thesis I will regularly revisit policy needs in light of the research I present and aim to reinforce the need to high-level discussions whilst presenting both broad-scale and fine-scale examples.

Table 3.3 - Interdisciplinary assessment of interventions in response to mosquito net fishing challenges in KAAs. *N.B. Numerous alternative vector control solutions exist or are in development but were not assessed by the group owing to a dearth of viable knowledge. Continued development and innovation was however a key output of the interventions discussion.

Intervention	Scalability	Cost-effectiveness	Collaborative requirements	Additionality	Information/data needs	Identified pitfalls
Mosquito-proof housing solutions e.g. eave tubes, screening, wall linings (current RBM focus)	Appropriate for most permanent/semi-permanent dwelling types.	More expensive than MNs but can be more durable. Protection for household over individuals.	Could operate through current health intervention bodies. Architectural and design engineers.	Minor housing improvements. Marginalised groups more likely to be covered.	General dwelling designs & family structures. Culturally appropriate aesthetics	Uptake hampered by aesthetics. Outdoor sleepers not covered.
Housing improvements	Need to adapt to dwelling types. Simplest dwellings may not be suitable or need additional work.	Highly context dependent. Dwellings needn't be fully proofed for effective protection. Very long-lasting.	Development sector. Private housing industries.	Benefits to general health, standard of living, social mobility. Knock-on benefits – able to invest in other improvements.	General dwelling designs & family structures Culturally appropriate aesthetics. Local capabilities.	Requires continued investment in maintenance. May exclude poorest households.
Increased indoor residual spraying (IRS)	Already prevalent – infrastructures exist in many places. Requires re-treatment ~2 years	Can be less cost-effective than MN distribution. Re-application every ~6 months.	Relatively specialist. Could be combined with other door-to-door activities.	Jobs for locals a win-win.	Local acceptability	Contributions to insecticide resistance. Safe use of DDT.

	and specialist treatment.	Protection for household over individuals.	Environmental management.			Aesthetics and smell not appealing. Invasive.
Increased use of spatial repellents e.g. coils, vapourisers	Successful use in lots of various settings. Many different products available – can adapt to environment. Continuous supply system needed.	Re-supply possibly costly. Could be made cheaper with increased use (bulk).	Social marketing & education. Modes of distribution.	Can use outdoors (currently area of increasing risk). Covers groups and individuals.	Local acceptability. Research in to efficacy in different environments. Health impacts (largely unknown)	Efficacy of different products variable – needs more research/recommendations list? Acceptability and use is variable.
Increased use of Larval Source Management e.g. community standing water management, larviciding	Already being scaled up, but localised tailoring needed.	Various different scales – from large operations on lakes to promotion of community LSM e.g. well covering	Specialists required. Community-LSM can be combined with other education & behaviour change messaging	N/A	Potential larval sources. Identification of hotspots.	Some methods may be damaging to environment and impact insecticide resistance – larviciding water bodies, introduced species, or large-scale habitat alteration.
Use of less durable/cotton nets (tear when used for fishing?)	Easy to switch to different nets but would need separate distribution	More need for re-distribution more frequently (less durable), significant	Significant policy change	N/A	Identification of high MNF-risk areas.	Creation of market to fishing communities for more durable nets distributed

		disadvantage over more durable nets			MNF net alteration methods – will this have desired effect?	elsewhere – premium on tough nets.
Community-based fisheries co-management (e.g. Locally Managed Marine Areas w/MNF exclusion)	Can be complicated initially but often models of co-management are replicable to a great degree.	Opportunity costs for some in the short term. Implementation costs can be high. Better, more sustainable incomes in long term.	Fisheries ministries, local NGOs (scientific guidance), development NGOs (e.g. gender mainstreaming), strong buy in from local leaders (relationship building) and fishers. Education & behaviour change.	Sustainable use of resources promoted throughout fishery = long-term food security. Community empowerment. Promotion of equity in resource use and inclusion of women aids development. Biodiversity protection.	Understanding of drivers of MNF locally (avoid harm). Detailed characterisation of fishery and market chain needed. State of relevant ecosystems/fish stocks.	Reliance on enforcement of MNF bans could hurt most vulnerable w/out appropriate alternatives. Migrant fishers can be excluded from management.
Alternative income generation (non-fishery e.g. alt. livelihoods (aquaculture), microcredits,	Needs to be locally specific (w/prior research) but generalised models can be followed.	Very costly set-up but with potentially very high returns.	Would work best if fully collaborative at range of scales with fisheries mgmt., development, conservation & health.	Huge additional benefits across communities – likely to be response to multiple issues inc. MNF. Can have impacts across all aspects of	In-depth characterisation of current livelihoods, local resources, opportunities viable for expansion, cultural influences,	Sustained input and effective monitoring/evaluation necessary. Need to ensure MNF-specific niche is filled.

Village Savings and Loans Associations)			Should be combined with community-based fisheries mgmt.	sustainable development.	available/growing markets.	Must address food and nutrition security. Focus on MNF can look like rewarding illegal activity.
Women's empowerment & gender mainstreaming (fishery and/or non-fishery)	Will require localised-tailoring, though some lessons are transferable.	Potentially costly but with very high returns.	Huge benefits could be reaped from increasing gender-research and inclusion across all sectors and operations, with a specific objective to understand and address role of MNF.	Shown to have large impact on overall development efforts, sustainable resource use, and human wellbeing.	Detailed planning to navigate cultural difficulties. Characterisation of current livelihoods. Identification of opportunities.	Culturally difficult in some regions. Requires sustained input.
Reduce net oversupply and improve distribution efficiency e.g. spot checks, household data verification	Could be scaled to all NMCPs or target KAAs.	Several aspects could be costly and require significant effort on top of distribution costs.	Collaborations with other on-the-ground organisations, particularly for data provision and evaluation, could significantly cut costs.	Waste reduction – impact on marine debris and landfill. Information collected would be useful for numerous other initiatives.	Detailed supply-chain information (not always available) Detailed census data alongside characterisation of localised living conditions.	Corruption may persist.

Promote positive net re-purposing for worn nets e.g. covering water bodies, use in agriculture	Could be scaled to all NMCPs.	Very cost-effective – additional value in MNs	Other sectors can reinforce messaging and advise on non-vector control uses that are safe/useful e.g. in agriculture. Education & behaviour change.	Waste reduction. Additional vector control e.g. larval source management by covering wells etc. Positive uses in food production, construction etc. (very useful resource)	Research in to local repurposing – what is potentially harmful?	Messaging may be confusing, sectoral priorities may have an influence. Impact on insecticide resistance will likely remain unknown.
Develop disposal mechanisms for 'end of life' nets	Very challenging in rural areas, and even some urban settings which lack existing waste-collection/disposal mechanisms.	Very expensive in areas with no current system. Even if just focused on MNs would require logistical costs.	Could operationally combine with a) MN distribution (e.g. exchange programme) or b) concerted effort to improve overall waste management by governments.	Could bring significant improvements to local sanitation, air quality (reduce open-air burns) and reduce ecological damage (marine litter, ghost fishing). Opportunity for energy generation with incinerator investment.	Tracking of distributed nets would need to be accurate for exchange programmes, net leakage at all scales could reduce coverage long term. Definition and mode of I.D. of 'end of life' nets.	Current WHO policy for safe final disposal is incineration – facilities may not exist.

Develop recycling mechanisms for 'end of life' nets	Expensive to facilitate through state. Community-collection model (e.g. Net-Works; net-works.com) could present scaling-up option.	Dependent on value of recycled products. Costly start-up.	Private sector involvement for research, marketing and investment. Circular economy advocates. NGOs (conservation or development)	Waste reduction. Community collection model brings additional incomes and microfinancing opportunities to communities.	Potential processes, products and markets. Receptiveness to community collection. Definition and mode of I.D. of 'end of life' nets.	Health-related issues from residual insecticides on products. In theory MNs should be a temporary resource (in elimination of malaria) – impact on investment? Commodification of MNs?
Alter net design – less fit-for-fishing and/or more fit-for-purpose e.g. biodegradable materials	Would depend on ultimate cost of product. Ideally would be tailored (physical design) to different scenarios so scaling not main priority	Unknown – costs would need to be kept low to be competitive.	Private sector & WHO (rapid assessments and recommendation). Can incorporate needs in to existing research. Combine with recycling/disposal research.	Enhancements to vector control efficacy. Increased social acceptability of MNs (e.g. more comfortable)	Nuanced understanding of flaws in current MN designs. Comprehensive review of deployment methods for fishing.	Potential for inappropriate MNs to be distributed to some communities.

4. Plenty more fishers in the sea

A global perspective on the distribution and characteristics of mosquito net fishing

4.1. Introduction

There remains limited peer reviewed literature pertaining to global patterns of MNF and what the influence of these freely distributed nets is on the more general use of small-mesh gears, particularly outside Africa. Indeed, I could find only brief mentions of MN use in fisheries of India, Bangladesh, Timor Leste, The Philippines and the Solomon Islands (Atkinson *et al.*, 2009; Devi *et al.*, 2013; Lover *et al.*, 2011; Siddique *et al.*, 2013; Silvestre & Federizon, 1987). Within this literature the reported user demographics, methods, perceived impacts and extent of MN fishing (if mentioned, which was rarely) are variable. Small-scale case studies are beginning to emerge with localised policy implications, which have also served to highlight the potential cultural and geographical heterogeneity of the issue (McLean *et al.*, 2014). In addition, these studies allude to an underappreciation of the prevalence and scope of MN use in fisheries, particularly in sub-Saharan Africa but also anywhere where MNs are distributed globally. As I have identified in Chapter 3, the lack of a global perspective on the extent and characteristics of MN fishing precludes the addressing of the higher-level, trans-boundary and multi-stakeholder policy implications of MN fishing. There has been no empirical investigation as to the actual extent and prevalence of MNF and there is an urgent need for better information on the global patterns of MNF if we are to begin to identify key affected areas for interventions.

In this chapter I address this need, building on the current limited literature by providing a rapid assessment of the current state of awareness and perceptions about MN fishing at a global scale as an initial scoping exercise to generate some indication of the prevalence and nature of MNF. I use an online survey of predominantly charity-sector workers to undertake a preliminary and broad-scale investigation in to the variability in who, how and why people use MNs for fishing, setting the scene for future detailed investigations at a finer resolution.

4.2. Methods

Online survey

An online survey was made available in English and French between 4/6/15 and 14/8/15 using the Qualtrics Survey Software (Snow, 2013). Information regarding MNF was requested from anyone living

or working within any area of malarial risk, either coastally or close to bodies of water used for fishing at any scale, with a focus on obtaining responses from relevant stakeholders in the fisheries management, public health, conservation and development sectors. By sampling these groups we deemed that relevant and detailed responses would be more likely, detail would be more reliable based on respondent experience and the survey would benefit from snowball distribution to relevant networks. Additionally, we deemed the online survey method to be the fastest and most cost-effective way of obtaining responses. Although this method excludes those without internet access and can suffer limitations in scope and uptake, this sampling strategy and target audience was used to attempt to maximise access (both in terms of internet connection and language), generate good quality data and rapidly glean a global perspective on an issue which is rarely a primary focus of any of these sectors.

Qualifying questions on, for example, time the respondent has spent at the location, organisational affiliation and associated role were used to gauge levels of confidence in observations. Two survey options were available: for individuals whose experience was predominantly fisheries/conservation/ecology focused, and for those whose experience was predominantly development/health focused. The latter omitted questions for which a higher level of ecological knowledge was necessary. We requested observations of MNF at the '*village level*' or equivalent but also accepted were '*areas of coastline, river, lake, fishing location or region'* if later geographically defined. Respondents could provide more than one observation by completing the survey for each location where they had first-hand, personal knowledge of MNF. We solicited both negative and positive observations of MNF in order to reduce positive bias. We included duplicate observations at given locations if additional information significant to the study objectives was provided.

We promoted this survey to relevant respondents through the authors' own networks, relevant mailing lists, newsletters, conference delegate lists and direct targeting of relevant individuals and subsequent networks through internet searches. Social media outlets Facebook and Twitter were utilised extensively with all authors' affiliated organisations participating and expanding the reach. Every effort was made to ensure geographical representation and to limit potential bias from factors such as prevalence of NGO activity in an area. Whilst negative observations are not conclusive evidence of absence, some confidence is afforded by the general visibility of MNF as an activity. Where deemed necessary and feasible, we contacted respondents directly for additional detail, reports, papers and photographic evidence.

4.3. Results

Ninety four observations of presence and 36 observations of absence of MNF were received from 113 respondents. Here we explore only presence observations, in order to guard against bias, but the absence records are given for information in the Supplementary Material. Fifty seven observations were given from those working in the conservation and ecology sector, 17 from development and health, 17 with a fisheries focus and 3 in relevant commercial or tourism roles (Table 4.1). One hundred and twenty six observations included specific location information.

Table 4.1 - Presence observations of MNF by region and work sector of respondent

Work sector	Americas	Asia	East Africa	Oceania	West & Central Africa	Grand total
Conservation	2	7	36	2	10	**57**
Development & Health		1	13		3	**17**
Fisheries mgmt.		3	11	1	2	**17**
Commercial & tourism			3			**3**
Total	**2**	**11**	**63**	**3**	**15**	**94**

Spatial and temporal prevalence of MNF

Reports of MNF presence came from 26 countries across all equatorial continents, 16 of which (74 responses) were in sub-Saharan Africa. Results highlighted the presence of MNF in 18 countries for which there were no previous records of MNF in the peer-reviewed literature (Figure 4.2). Eight of the countries with records of MNF in the literature were not represented in our survey. Globally, 66% of location observations were in marine environments and 34% in freshwater.

Reports from Asia were clustered in the Philippines and Bangladesh (Appendix 4.2) and were predominantly coastal, with the exception of Nepal. Papua New Guinea and American Samoa had the only observations in the Oceania region.

Observations of the presence of MNF from the Africa region were heavily skewed towards the sub-Saharan, Indian Ocean nations with an additional cluster of observations around the African Great Lakes (Figure 4.2). In Madagascar, 16 observations (the highest of any country) covered much of the coastline, as well as Lac Alaotra, the largest freshwater body. Observations were also made inland large distances from substantial bodies of water in riverine environments. Only two presence observations were made in the Americas – in Honduras and Ecuador.

Seventy four observations included the first year in which they observed MNF at that location. A cumulative frequency curve (Figure 4.1) shows a steady rise in first observations beginning in the mid-1970s and continuing until the present day, corresponding closely with the Alliance for Malaria Prevention's net distribution figures which are available from 2004 (AMP, 2017). This trend holds across Asia, East Africa and West and Central Africa.

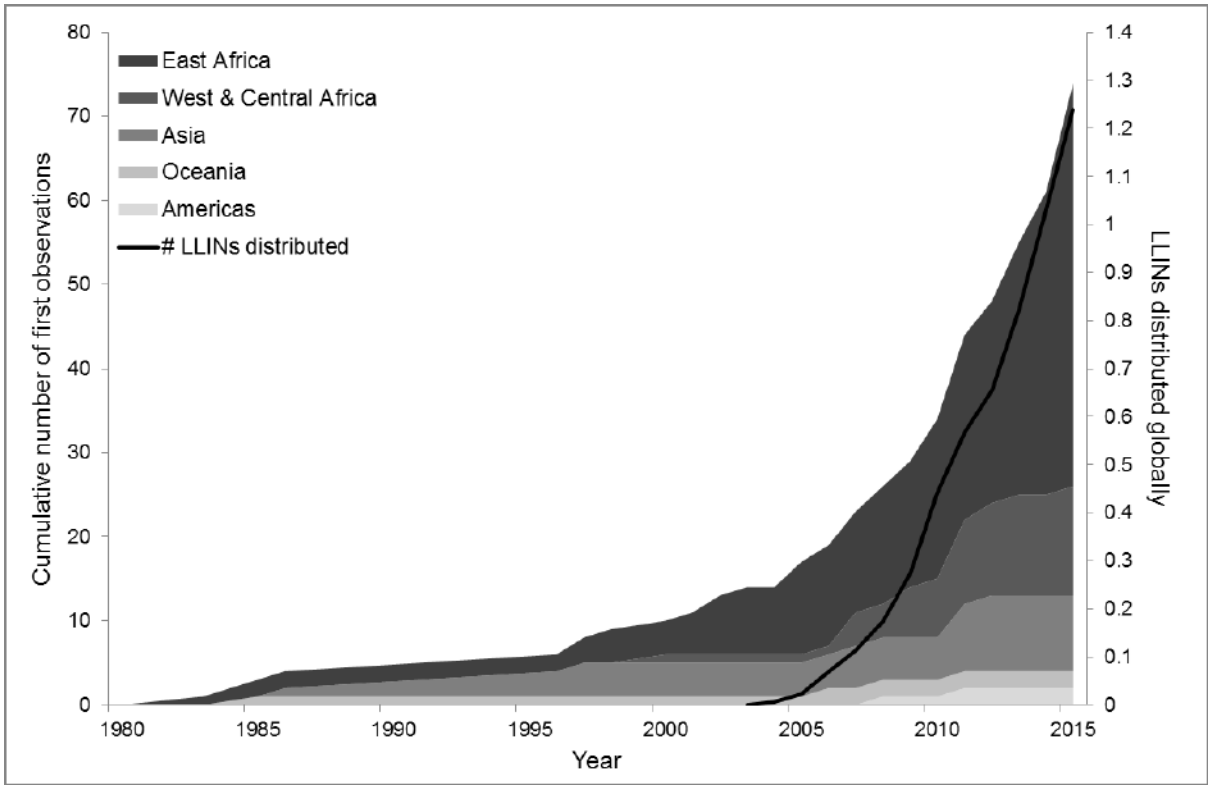


Figure 4.1 - Cumulative first observations of MNF by region. Black line represents Global cumulative number of Long Lasting Insecticide-treated nets (LLINs) distributed since launch of Roll Back Malaria Programme, net data from The Alliance for Malaria Prevention NMP

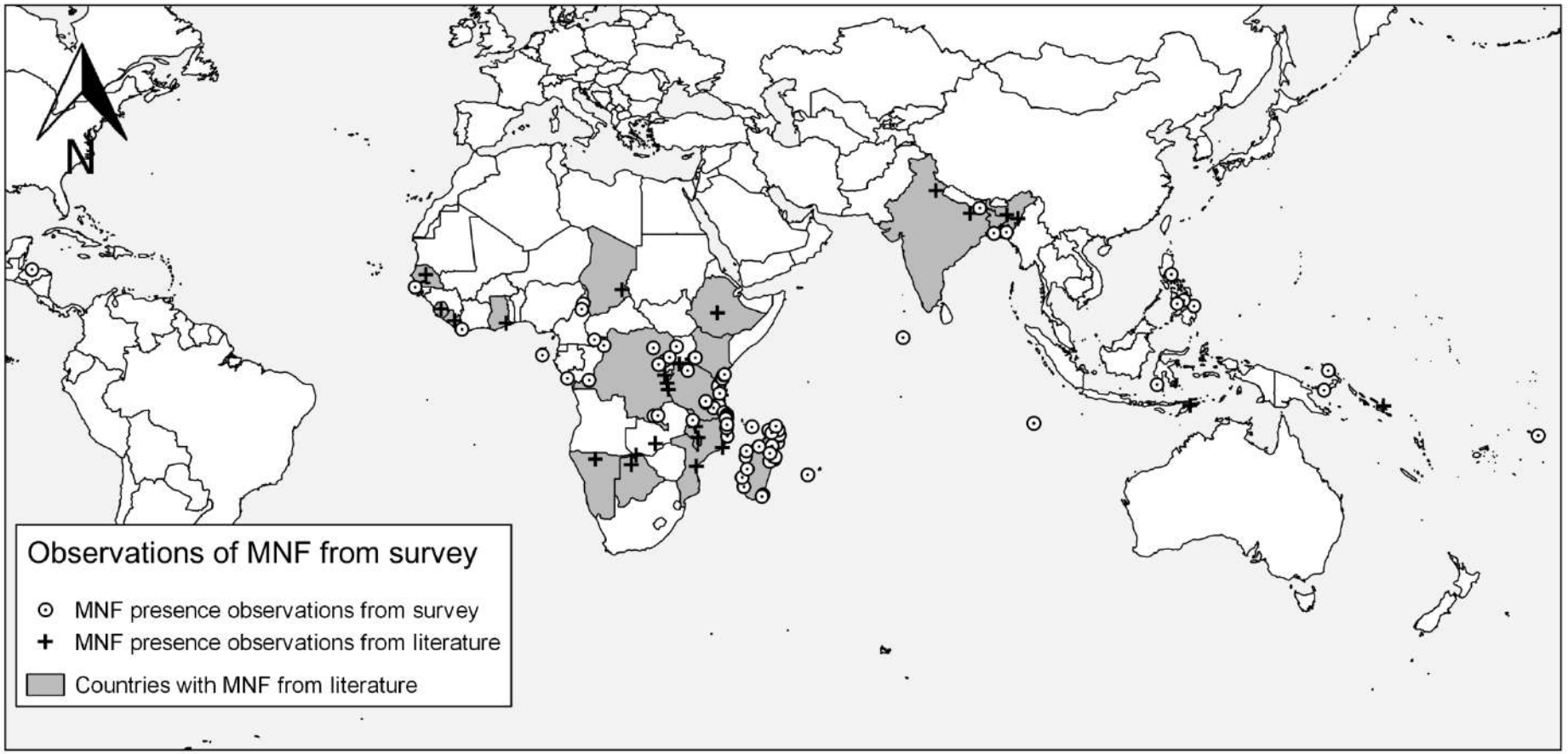


Figure 4.2 - Global map of survey responses showing presence reports of MNF from the survey and confirmed locations from the existing literature.

Biome reporting rates and habitat use

One hundred and eight reports of biomes associated with MNF were given: 59% coastal, 13% lacustrine, 25% riverine and 3% wetlands. Of 177 responses for specific habitat use the majority (31%) report MNF use on beaches/sandflats, twice as many as in seagrass beds and mangroves (Table 4.2). MNF was reported across all marine and freshwater habitats in both Africa and Asia (Figure 4.3).

Table 4.2 - Proportion of responses reporting MNF activity in different habitats globally

Habitat	Proportion total obs (n = 177)
Beach/sandflat	0.31
Seagrass bed	0.15
Mangrove	0.14
River	0.13
Pelagic	0.08
Lake	0.07
Local stream	0.07
Coral reef	0.05

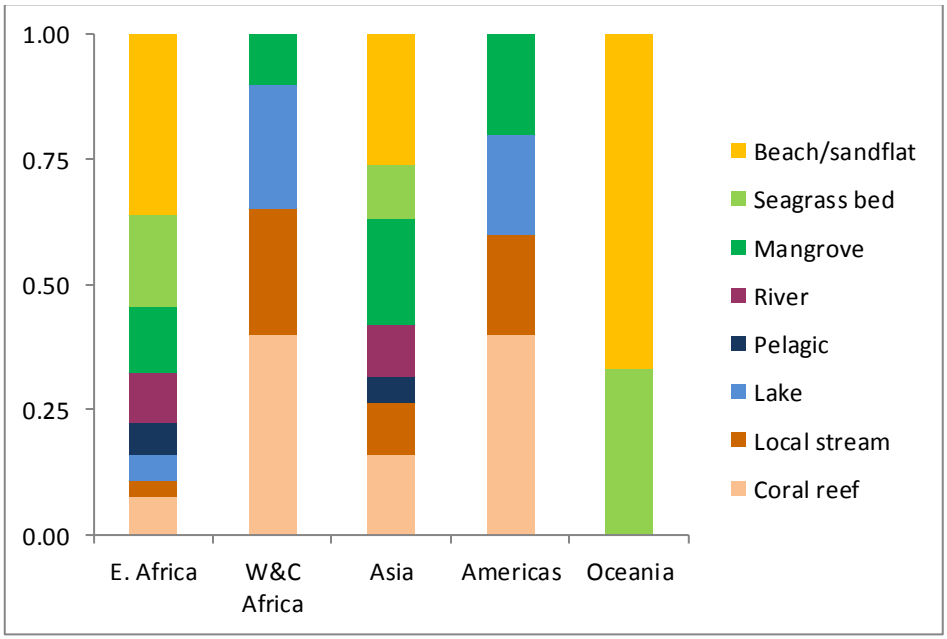


Figure 4.3 - Proportion of habitats utilised by MN fishers reported by region.

Gear characterisation and deployment

The majority of respondents reported that deployment took place on foot (60%, n=115), but with canoe use also featuring prominently (29%), particularly in W&C Africa. MNF from sail and motorised boats was also reported across all three regions.

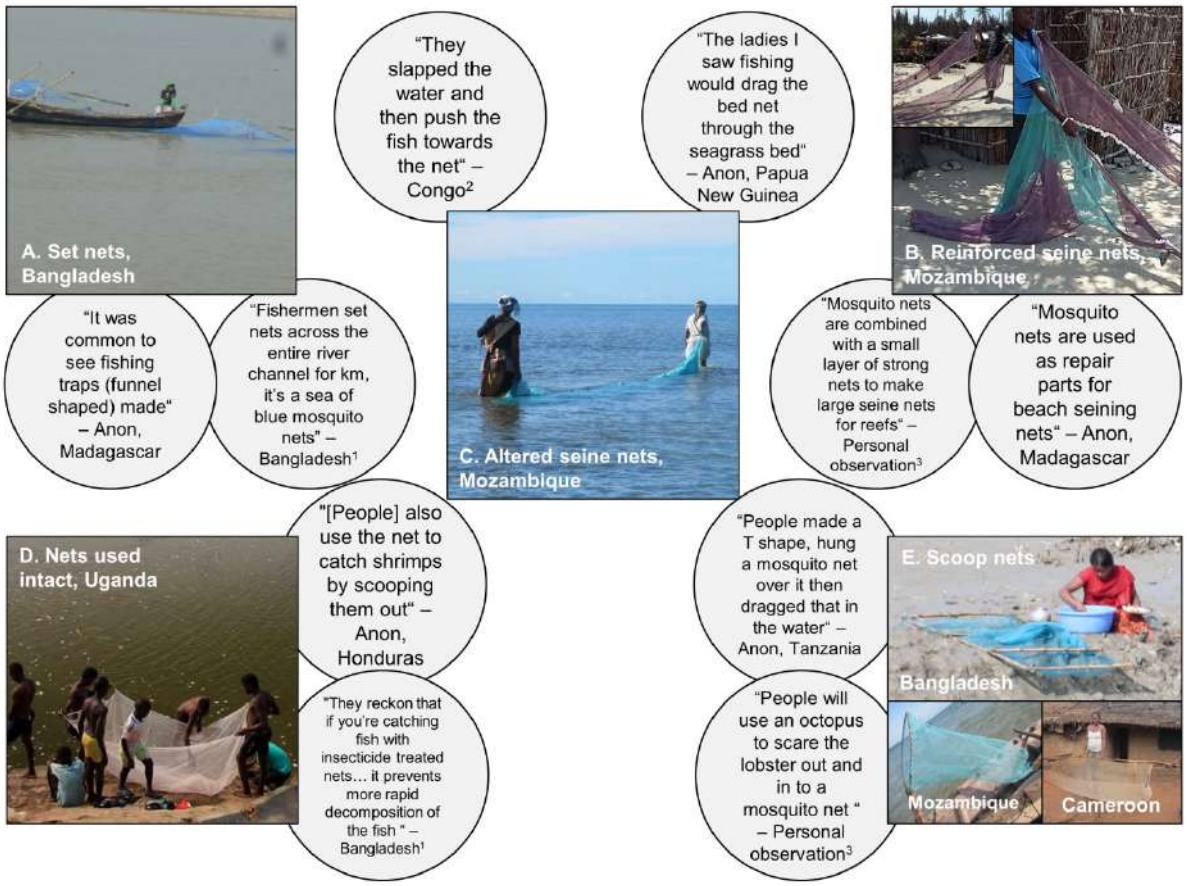


Figure 4.4 - Summary of additional information provided by respondents.

Photo credits: A) R. C. Browmick, B+C) R. Short, D) C. Hopkins, E) Bangladesh - N. Dewhurst-Richman, Mozambique – R. Short, Cameroon – J. Wright

[1]Nadia Dewhurst-Richman, Zoological Society of London; [2]Petra Lahann, German Development Corporation; [3]Rebecca Short, Imperial College London.

Four predominant MNF methods were identified from the literature, and clarified further by our survey: Single-net use, with nets largely unaltered and operated by individuals or pairs, dominated across all regions (53%, n=105), followed by multiple nets sewn together for use by small groups of fishers (34%), then use as a cod end of larger seine nets (10%) and finally just three reports of insecticide fishing, the details of which remain unconfirmed but where in one case additional DDT is thrown in to the water along with the MNs. Numerous other methods were described by survey

respondents, including a number of trap designs, 'scoop' or 'dip' nets, and the use of static 'set' nets used to funnel fish, sometimes with photographic evidence (Figure 4.4).

Demographics of MN users

The reported frequency of engagement in MNF varied significantly across demographic groups, with women most commonly reported as engaging in MNF 'often', and men, children and the elderly most commonly reported as engaging in MNF 'sometimes' (Figure 4.5, X-squared = 38.94, df = 6, Cramer's V = 0.27, p = <0.001). There was no significant regional difference in this trend (omitting Oceania and the Americas due to low response rates; X-squared = 4.67, df = 6, Cramer's V = 0.10, p-value = 0.59).

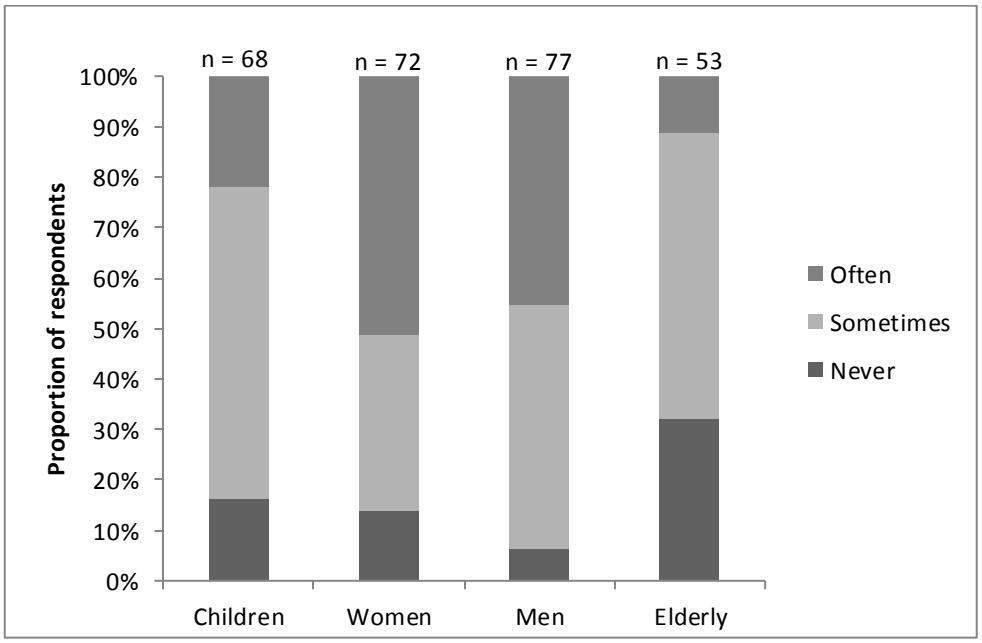


Figure 4.5 - Demographics of proportion of the observed population engaging in MNF either 'often', 'sometimes' or 'never'.

Thirty five percent of observations reported those engaging in MNF to be experienced fishers, 43% part time and 21% inexperienced fishers. In terms of occupational diversity, of 128 observations 28% reported that MN fishers also fish with other gears, 34% agriculture, 15% small business ownership and 23% casual labour. Other observations included formal employment and tourism.

Observed restrictions on MNF

Fifty (38%) of the observations confirmed the existence of some kind of formal legal local or national restriction with a bearing on MNF activity, while two stated that restrictions did not exist. Of the restrictions, two (in 2 countries) were seasonal, the remaining 48 (12 countries) were year-round. Of the 19 respondents who were able to elaborate, 11 reported that they were based on existing laws concerning mesh size limits, six were specific laws for mosquito nets and two were based on seasonal

management. A further 11 respondents reported some kind of local and/or informal restrictions such as Malagasy 'Dinas' (community-enforced rules), however few respondents were able to provide further detail.

Species caught

Response rates were low for questions relating to taxonomic and maturity composition of MN catch; anything speculative was removed from the dataset and only confident instances retained. Thirty-eight families of fish were identified as present in MN catch across methods, habitats and regions; 7 freshwater and 33 marine (Table 4.3). Additionally, general reports of squid, crabs and shrimp were made, with the last of these identified as a significant component of coastal MNF catch. Particularly high value species targeted included seahorses in Papua New Guinea (Chinese Traditional Medicine market-driven).

Table 4.3 - Families identified by observations in MNF catch. NB – maturity status was not individually obtained for families so groupings are based on general associations at adult life stages.

Reef/seagrass associated	Pelagic/neritic associated	Freshwater
Acanthuridae	Ariidae	Alestidae
Balistidae	Atherinidae	Aplocheilidae
Caesonidae	Carangidae	Characidae
Chaetodonidae	Chanidae	Cichlidae
Epinephelinae	Clupidae	Clupidae
Gobiidae	Drepaneidae	Cyprinidae
Haemulidae	Elopidae	Gobiidae
Holocentridae	Engraulidae	
Labridae	Gerridae	
Lethrinidae	Leiognathidae	
Lutjanidae	Mugilidae	
Mullidae	Scombridae	
Platycephalidae	Sparidae	
Pomacentridae		
Scaridae		
Sciaenidae		
Serranidae		
Siganidae		
Syngnathidae		
Tetradaontidae		

Fifty-nine respondents cited presence of juveniles in MN catch. Of 69 respondents identifying important targeted taxa at a generalised level, 29 reported targeting of reef-associated fish, 13 pelagic/neritic species, 6 molluscs and 14 Crustacea (Table 4.3).

Species that were frequently reported as significant targets for MN fishers were:

- Marine shrimp species: all regions.
- The Common silver biddy (*Gerres oyena* and similar species): known as 'Sala' in E. Africa.
- Milkfish (*Chanos chanos*): both African and Asian fisheries, often targeted for wild-caught fry aquaculture.
- Silver cyprinid (*Rastrineobola argentea*): commonly known as 'Dagaa' or 'Omena' in the fisheries of Lake Victoria.
- Lake Malawi sardine (*Engraulicypris sardella*): known as 'Usipa', fisheries of Lake Malawi.

Perceptions of MNF drivers and impacts

The majority of respondents observed MNF catch to be locally important for both consumption and sale (66%, n=87). Additionally, the use of MNF catch as bait for other gears was identified, along with large scale sale to animal feed companies in Madagascar.

Perceived drivers of MNF were dominated by the incentives (pull factors) of readily available nets, convenience of the method/catch and good catch, along with the forcing, push factor of poverty, followed by perceived declines in alternative resources (Figure 4.6). Qualitative responses of note include: one report of MNs deliberately distributed to communities in Papua New Guinea by Chinese traders targeting seahorses for the Chinese Traditional Medicine market, and another report of MNF in Madagascar driven by demand from animal feed companies targeting forage fish.

Respondents speculated that people may choose not to fish with MNs due to perceptions of unsustainability, risk of mosquito-borne diseases, prohibition, and preference for alternative occupations. A lack of access to MNs ranked sixth in this list, suggesting this is not often a limiting factor and nets are considered widely available.

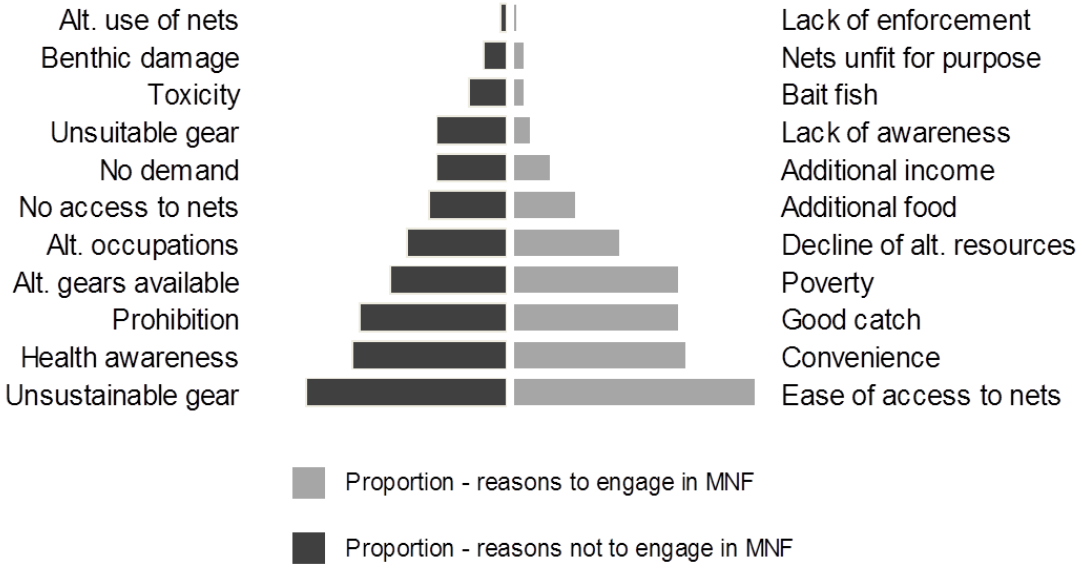


Figure 4.6 - Proportion of observations citing various drivers for people engaging and factors that may influence people not to MN fish.

4.4. Discussion

Concerns over the use of MNs in artisanal fisheries have been expressed in disparate locations in the peer-reviewed literature since the early 2000s but have thus far lacked formal investigation at a global scale. It has been proposed that the impacts of MNF are likely to relate to both the selectivity of the fine mesh nets, and also to the potential for increased fishing pressure resulting from the nets' availability and ease of use. Therefore it is important to begin to understand both the characteristics of the fishery and also the current distribution and prevalence of MNF. This study aims to gather information on experts' awareness and perceptions of MNF in order to broadly characterise MNF globally, and gain valuable insights from those witnessing the activity in order to highlight research needs and catalyse debate across stakeholder groups.

Characterising the global prevalence of MNF

A critical question posed by the public health community when engaged on the issue of MNF and whether or not a policy response is required is: how widespread of an issue is it? Is it just isolated pockets on a few lakeshores or engaged in by multiple people in multiple communities? Here we have aimed to answer these questions to a degree necessary to catalyse an appropriate response. MNF is widely represented across all equatorial regions; our survey results confirm presence of the activity in most regions classified as 'at risk' areas for malarial transmission, save for European and Middle Eastern regions. This distribution correlates with regions where efforts to supply free and/or subsidised

MNs as part of anti-malarial efforts are particularly pervasive (WHO, 2015). Although it is unwise to infer absolute levels of prevalence of MNF by region from a non-random survey, recent suggestions of rapid increases in MNF activity in the East African region in the media, peer reviewed and grey literature (Bush *et al.*, 2016; Darkey & Turatsinze, 2014; Gettleman, 2015; McLean *et al.*, 2014) appear to be supported by our results, with a high concentration of reports both coastally and around the African Great Lakes. However, high response rates from Mozambique and Madagascar may be influenced by well-established networks of NGOs operating in the region that were able to distribute the survey widely.

The cumulative frequency of first observations (Figure 4.1) appears to align with the cumulative number of nets distributed globally; according to the Alliance for Malaria Prevention (LLINs only are presented here, other nets have been distributed but not on a similar scale). The launch of WHO's Roll Back Malaria (RBM) programme in 1998 had the goal of unifying public and private efforts towards tackling malaria globally. Goals were set for universal coverage of bed nets for those living in at-risk areas. A few years later large scale distribution programmes began globally, but with a particular focus on sub-Saharan Africa (WHO, 2015). These results may therefore reflect the rise in MN distribution campaigns under the WHO malaria programme. However, they should be treated with caution as just ten respondents had witnessed the introduction of the activity personally (as opposed to on their arrival in an area). There are also well documented issues of recall accuracy and the fact that observer presence has increased in recent years stems from increased NGO activity in many regions, whether health or environment-focused.

Differences in reported prevalence of MNF in Africa and Asia point towards a possible link between MNF and MN-distribution efforts. Net distribution efforts in Asia are considerably lower than in sub-Saharan Africa. Although internal national efforts exist, 82% of international investment has been directed to Africa (WHO, 2015), so net availability may be a contributing factor. The activity may also have a different level of visibility in Asia where small mesh nets in general are more common and MNs may be indistinguishable from other materials. The limited information gleaned for the Americas and Oceania, despite confirming presence of MNF from at least two sites in each region, does not support any broad inferences as to prevalence.

Although the limited peer reviewed literature incorporating information on MNF is largely focussed on freshwater environments (Abbott & Campbell, 2009; Hamerlynck *et al.*, 2011; McLean *et al.*, 2014; Minakawa *et al.*, 2008), our survey suggests that MNF is widespread and frequent in marine environments. We can also infer that where MNF has been reported to occur (marine or freshwater) it is a frequent and perennial activity. This could indicate that MNF has become part of daily livelihood

and/or consumption portfolios for at least certain user groups. Consideration of livelihoods is therefore of great importance when designing interventions/policy options.

Variability in MNF characteristics

Most deployment appears to remain small-scale, with the use of one or a few nets sewn together as small-scale seine nets in shallow-water environments. Use on coral reefs was reported infrequently and anecdotal information suggests that MNs are largely unsuitable for this environment due to frequent tearing.

Shallow water environments such as seagrass beds, sand flats and mangroves can host large biomasses of fish (Robertson & Duke, 1990) which may have been less accessible and/or desirable before the advent of MNF. Although similar, traditional fishing methods using cloth are documented and associated with MNF communities in the survey, such as 'Tandilo' in East Africa, (Bush *et al.*, 2016) their efficacy is likely to be lower than MNF but precisely what impact the addition of MNs may be having cannot be inferred from this study. As long as people have a use or market for the associated species then it can be inferred that MNs may confer an important advantage to users either as an additional gear or an alternative livelihood choice. Use in shallow water may also mean that MN fishers can continue to engage in traditionally widespread gleaning activities for resources such as octopus and molluscs concurrently.

Implications for management

Our results support the suggestion that MNF is a highly accessible fishing activity which doesn't require the skill, knowledge, vessels, opportunity costs or capital investment necessary for other fishing gears. Looking at motivations from a 'push' or 'pull' perspective, the perceived drivers cited by observers are dominated by pull factors; positive reasons why one would choose to MN fish, and underlying this was the predominant push factor of poverty. The real variation in drivers, important to intervention design, may lie in the user groups. For those users already classified as 'vulnerable' or 'marginalised', MNF offers an opportunity to reduce this vulnerability. In many traditional artisanal fisheries women play a vital supporting role in processing and sales of fish, and are also involved in gleaning (Bennett, 2005). However, in many places women are still considered a marginalised and vulnerable group because of cultural norms that limit their access to fisheries (Kleiber, Harris & Vincent, 2015). MNF represents a more efficient method for traditional gleaning that could generate higher returns. Our data also suggest that the experience levels of fishers are variable and that occupational multiplicity is common amongst those engaging in MNF. This may be particularly important for traditional farmers and natural resource users driven off their land by climate change or changing land uses and resettlements (Bunce,

Rosendo & Brown, 2010). For example, the Giriama in coastal Kenya were settled in Mida Creek as a result of resettlement and took up MNF (Bush *et al.*, 2016).

If MNF becomes increasingly attractive economically, either due to other fisheries declining or development of new markets, this could increase male engagement in cases where MNF is currently deemed 'women's work' (e.g. seaweed farming in Tanzania, at first undertaken predominantly by women, was later dominated by men once its commercial value was deemed sufficient (Porter *et al.*, 2008)). Market-based factors such as the ever-growing reach and size of the Chinese Traditional Medicine and animal/aquaculture feed markets may drive these changes.

Respondents' perceptions of reasons not to engage in MNF most commonly alluded to fishers' perceptions of the unsustainability of the practice. These perceptions are of course from people external to the fishery; in reality this motivation is likely to vary widely between user groups depending on an interaction between people's perceptions, ecological understanding and the degree with which they engage/rely on the wider fishery. Awareness of the health benefits from correct use of MNs is second-most cited and there are examples in the literature of increased awareness-raising impacting levels of alternative MN use (Desrochers *et al.*, 2014; McLean *et al.*, 2014). These efforts are likely to be impacted by overall availability of nets. For example Bush et al., (2016) found that in Mida Creek, Kenya there was unlikely to be a trade-off between malaria prevention and MNF as nets were so readily available.

This chapter was not an empirical investigation into the sustainability of MNF. We therefore do not present conclusions on the ecological impacts of MNF, but our findings do give useful preliminary insights to guide future research. The observations of catch composition and juvenile capture do lend us some critical first insights that may support and oppose current concerns, but certainly illustrate the need for further investigation. The diversity of marine MNF catch is likely to be due to the utilisation of habitats such as seagrass beds and mangroves for MNF, which are important nursery grounds for both pelagic and reef-associated species (Mumby *et al.*, 2004). The range of families and functional/trophic groups reportedly caught in MNs in the marine environment is of concern for selective fishing management regimes. Some species and/or life history stages targeted are those for which there was limited former demand (e.g. juvenile *Gerres oyena*), potentially expanding fishing impacts, but also providing a potentially valuable new resource. Fish also often occupy multiple niches at different life stages. Exploitation of a species at an increasing number of these life stages could be disruptive at the ecosystem level, or may conversely contribute to a more balanced harvest-type scenario with increased overall yields if managed appropriately.

Reports of high juvenile capture rates are also of concern in both marine and freshwater environments where conventional management is a goal. Although it is impossible to verify the specific biological knowledge of every respondent, enough respondents were able to identify fish to family or species level, and verify juvenile capture at this scale to warrant investigation. Within the literature this is the biggest concern pertaining to MNF due to the undermining of size-selective management (McLean *et al.*, 2014), and the potential for growth and/or recruitment overfishing of stocks that are relied upon by other user groups. However, size-selective management, as well as being generally inappropriate and prohibitively difficult to implement in artisanal scenarios, is no longer the only accepted management discourse. Particularly where food security is the biggest concern and where wet weight of protein may be prioritised over rents, balanced harvest is increasingly thought of as a more pragmatic approach to management (Plank *et al.*, 2017) and to achieving new goals of ecosystem-based management (Garcia *et al.*, 2012). It is worth considering, therefore, the critical importance of understanding the user groups for MNF and their vulnerability alongside empirical assessments of their impacts on a fishery. Strong arguments exist for an underestimated importance of the harvesting of small bodied fish in subsistence communities (Kolding & van Zwieten, 2011). MNF investigations should not disregard a potential synergy with ecosystem-based management goals and benefits posited by balanced harvest theory including increased protein provision and positive contributions to nutrition through micro-nutrients, particularly for children (Kolding, van Zwieten & Mosepele, 2015). Small mesh nets may play an important role in optimising yields (albeit of potentially low-economic value catch by western standards) in a balanced harvest scenario which, coupled with the accessibility of MNF, could contribute in a significant way to social equity and overall food security. Though this consideration of social equity is deeply complicated by the health element of the MNF issue, the distribution of nets for anti-malarial purposes hinging importantly on collective compliance, it will nevertheless be critical to development of effective management interventions.

External to the debate over the direct impacts of MNF on the target fishery resource, however, reports of habitat damage are worrying in fragile habitats such as seagrasses where regular seining and trampling may have long term impacts. Also of concern are emerging market-based drivers, such as the Chinese Traditional Medicine and animal feed examples which are new to some of these areas, wherein external influences are introduced and environmentally and economically destructive behaviours encouraged.

Future directions

The aim of this study was to set the stage globally and identify the current state of, and gaps in, knowledge to guide future research in this novel arena. Although this is a global review, the issue

requires localised research. Therefore, we advocate for a portfolio of case studies with which to inform policy at the local level, while providing broader insights, aiming to:

a) Identify and map linkages between areas where MNF currently occurs/is expanding and potential driving influences such as prevalence and characteristics of net distribution, estimates of net 'availability' and net 'leakage', resource management capacity, broad fishery types and gear availability/accessibility. This will require a broad cross-disciplinary approach including data and knowledge sharing.
b) Empirically assess ecological impacts across the scale of MN use. Studies need to qualify and quantify the direct impacts faced in terms of overexploitation and interactions of indirect impacts such as habitat damage. Predictive modelling coupled with empirical studies would allow us to understand how this might impact fisheries more broadly.
c) Understand specific drivers of MNF for different user groups at a local level, being mindful of varying vulnerability and the potential for indirect drivers of MNF within coupled socio-ecological systems, particularly emerging market forces.
d) Determine the level to which MNF has become entrenched as a livelihood and/or subsistence activity within communities and user groups, and therefore the potential difficulties of reducing MNF.
e) Investigate how MN distribution efforts interact with MNF e.g. is growth in MNF correlated with specific net characteristics; do free vs. subsidised policies have an impact on MNF levels and if so why; does temporal spacing between re-distributions impact MNF and if so why; what effect might net retrieval schemes have?
f) Conduct assessments of localised institutional capacity for management, both formal and informal, with a focus on inclusion of vulnerable groups.
g) Collate and assess examples of interventions which have addressed the drivers of MNF, not merely reduced incidence, such as education and awareness programs, livelihood interventions, integrated gear management efforts.

All of these research strands need to be pulled together to inform a fully collaborative interdisciplinary approach to the issue. The perception data presented here indicate that the drivers of MNF are complex and may be influenced by policy change in both fisheries management and healthcare interventions. Therefore we hope that this research can act as a catalyst for collaboration between the health, fisheries management and conservation sectors. MNF is global, expanding and complex. Whilst strides are made to eradicate malaria, mitigation of unwanted and unforeseen consequences to natural resource sustainability must be of priority to avoid additional harm to developing nations' fishing communities and indeed potentially negative feedbacks on human health. Additionally, it will

be important not to lose sight of the ecosystems and biodiversity at stake, making MNF a conservation issue. Biodiversity conservation strives for a 'do no harm' approach to interventions, increasingly seeking to marry development and conservation towards mutual sustainability goals. We would advocate for similar principles being adhered to in antimalarial efforts and in an interdisciplinary approach to this problem, seeking collaborations toward outcomes that minimise social and environmental impacts in pursuit of malaria control.

5. Catch 'em while they're young?

Investigating assumptions about the ecological implications of mosquito net fishing in Northern Mozambique

5.1. Introduction

In chapters 2, 3 and 4 I demonstrated the highly contextual nature of MNF and highlighted the need for localised case studies to begin to inform management of relevant socio-ecological systems at a finer scale. It will be increasingly important to understand how the crucial feedbacks between health, environment and livelihoods outlined in chapter 2 manifest in individual communities to guide higher-level policies. Central to this, and pivotal to next steps for policy (Chapter 3), is determining actual impacts of MNF on the sustainability of individual fisheries, alongside a better understanding of what this means for associated biodiversity as whole. Whilst policies have been implemented in numerous countries to tackle MNF, largely enforcement-based (Bush *et al.*, 2016), these remain lacking in any evidence-base and are advocated for based on the ecological assumptions outlined in detail in chapter 2. However, case studies for MNF which draw on empirical catch data to test these assumptions are extremely limited (Manase *et al.*, 2002; Mulimbwa, Sarvala & Micha, 2018) and no evidence of monitoring programmes (targeted or otherwise) by government ministries for this gear anywhere in the world. Both baseline setting and continued monitoring are critical to understanding the role of MNF in socio-ecological systems and guiding successful fisheries management (Kittinger *et al.*, 2013; Bladon *et al.*, 2018), particularly co-management and adaptive management initiatives which aim to increase resilience and be adaptable to environmental and social change (Carlsson & Berkes, 2005).

Legally restricted gears may be deemed unnecessary or unfeasible to monitor, as given successful management their use would be minimised, and their illegality means that fishers are less likely to co-operate with data collectors for fear of reprisal (Pitcher *et al.*, 2002). Independent efforts by researchers may be subject to impacts of local taboos and social stigmas attached to activities seen as damaging; prohibiting fishers from engaging in monitoring activities. Added to which, MNF is easily theorised as a difficult activity to monitor, particularly in marine environments comprising highly biodiverse habitats such as coral reefs, where catches may be expected to be particularly mixed (Mangi & Roberts, 2006). The perceived tendency of MNF to catch many small individuals (Chapter 4) which may not be easily identified, particularly where deployment methods such as seine netting may damage the fish and their identifying characteristics such as fins, or fish are in larval form, may make accurate in-situ data difficult to obtain. MNF reportedly occurs in countries and regions where monitoring capacity may be low both in terms of skill and scale (Andrew *et al.*, 2007), and a lack of

precedent from established monitoring prohibits effective training for both government ministries and NGOs attempting to assess MNF. The subsistence nature of the activity and its use in rural communities means traditional landing sites and/or trading locations may not be used by fishers (Chapter 4), so locating fishers as they return from fishing trips may be challenging.

Despite these difficulties, which may understandably predispose managers towards erring on the side of restriction rather than monitoring and management of MNF, current restrictive policies specific to MNF may be considered short-sighted for two main reasons: a) policy responses which lack an evidence-base are often doomed to fail due to aspects not fully understood at the time of implementation, or may severely negatively impact their target groups, potentially forcing users towards 'worse' options (Chuenpagdee & Jentoft, 2007) and b) MNF is likely to be extremely difficult to police given the locations, environments and potential poverty drivers of the activity (Darkey & Turatsinze, 2014; Chapter 4), meaning that in the absence of monitoring, MNF is likely to continue but with managers in ignorance of its drivers and impacts whatever the enforcement response. Arguably, countries and regions where restrictive enforcement policies already exist for MNF are most in need of investigation.

Here we investigate the validity of some of the assumptions currently guiding policy, as they pertain to the marine fisheries of Palma and Mocímboa da Praia districts in Cabo Delgado Province, Northern Mozambique; fishing communities targeted by the OSOL project. This fishery suffers from all of the logistical issues mentioned above (Samoilys *et al.*, 2018) and, although governing bodies have been aware of an increase in MNF activities in the area, monitoring has not been established. The Instituto de Investigacao Pesqueira (IIP) are responsible for data collection and monitoring of artisanal fisheries in Cabo Delgado but consider MNF monitoring as outside of their remit owing to its illegality (IIP Provincial Director, Pers. Comms.). However, in order to facilitate co-management development as part of the OSOL project, a better understanding of the role of MNF in the fishery is necessary. Co-management legislation has existed in Mozambique since 1998 and grants powers to an elected village Conselhos Comunitários de Pesca (CCP – community fishing council) with theoretical support from the National Institute for the Development of Small scale Fisheries (IDPPE) and the Provincial Fisheries Administration (ADNAPE), though often more tangible support is provided by NGOs such as AMA and ZSL (Menezes, Smardon & de Almeida, 2009).

The devolution of power to local communities was, in large part, due to conflicts arising over issues such as the increasing use of fine-mesh nets such as MNs (Menezes, Smardon & de Almeida, 2009). Since the OSOL project began in 2014 new legislation has been introduced to try to further discourage MNF in Mozambique, including the introduction of a potential prison sentence of 3-5 years (IIP

Regional Director, Pers. Comms.). This has led to significant concern for those currently potentially dependent on the activity. Anecdotal evidence of the impacts of this legislation has been documented by the project team, including strongly negative local reactions to confiscation of MNF gears and testimonies from CCPs professing ethical conflicts in enacting their enforcement duties. Following discussions with provincial administration (ADNAPE) an informal agreement was reached in 2016 to reduce promotion of active enforcement in the short term, to allow this project and particularly the MNF research to go ahead.

The marine fisheries of Cabo Delgado are of mixed gear and catch, made up of subsistence and artisanal fishers who make use of the large intertidal, shallow reef and shallow-pelagic resources along the mainland and surrounding the islands of the Quirimbas archipelago (Samoilys et al., in press). Cabo Delgado is largely a poor (relative to national levels), isolated and understudied region of Mozambique where fisheries extent is limited mainly by access to gears (Garnier *et al.*, 2008). There are limited in-depth studies of the fishing communities and ecology of the region, mainly focusing on the island communities of the Quirimbas archipelago (Garnier *et al.*, 2008; Samoilys *et al.*, 2011; Gell & Whittington, 2002; Garnier *et al.*, 2008; da Silva *et al.*, 2015; WIOMSA, 2011).

Recent attention has been given to the villages north of Pemba city by research as part of both the OSOL project and an ESPA programme led by Exeter University (Sustainable Poverty Alleviation from Coastal Ecosystem Services – SPACES), the preliminary results of which I will draw on here for context but which are largely not yet published. The region in general is appreciated as a biodiversity hotspot with relatively healthy reefs of likely importance nationally and regionally, earning a recommendation for World Heritage status for its coral reefs (Obura, 2012) and the most extensive mangroves in the region (Pereira *et al.*, 2014). However, these healthy reefs are threatened by extractive activities such as removal of coral for building material (Rosendo *et al.*, 2011) and recent oil and gas discoveries, as well as increased fishing pressure from international and national migrants, largely from Tanzania and Nampula province who have been displaced by enforcement of gear bans. As a consequence fish populations are in decline (Rosendo *et al.*, 2011; McClanahan & Muthiga, 2017; Samoilys *et al.*, 2011). Locally-generated fishing pressure is also theorised to be growing as traditional fishing-farming communities direct more efforts to fishing due reduced agricultural productivity caused by pests, droughts and increasingly unpredictable seasons (Rosendo *et al.*, 2011).

Despite concerns over fishery sustainability and the influence of migrant fishers, gear use remains small-scale and low-tech compared with the typical gears of neighbouring Tanzania and also Kenya. The predominant legal gears used are described below in Figure 5.1, based on information from extensive personal observations by OSOL staff and myself, alongside preliminary results from SPACES

research (Julien & Januchowski-Hartley, n.d.). Vessels are largely limited to canoes for 1-3 fishers, sail boats (Dhows) for up to ~20 fishers and a very few motorised boats which may fish, but are also often employed for transport of goods and people.

The OSOL village sites of Lalane, Nsangue Ponta, Quifuque, Quirinde, Quiwia and Malinde (Figure 1.2) are all sites where MNF occurs, to varying degrees, as an additional but illegal activity. A household census performed by the OSOL team in 2014 at the start of the project aimed to quantify gear use across the villages (Samoilys *et al.*, 2018) and found a higher than anticipated rate of engagement in MNF, with up to 42% of fishers engaging (this highest figure being in Malinde village) and an overall rate in the region of 27% (Table 5.1), the highest usage rate of any gear. To date, however, the MN fishery has not been characterised and no empirical data has been collected or assessed for this gear by either the government or independent bodies.

Table 5.1 - Percentage of fishers citing predominant gear use across all six sites (adapted from Samoilys et al., 2018, in press)

Gear	% fishers
Mosquito net	27%
Gleaning (inc. harpoon)	15%
Hand line	14%
Spear	12%
Gill net	9%
Beach seine	8%
Speargun	8%
Basket trap	3%
Other	4%

Spear: sharpened metal rod with elasticated handle to allow use as short-range projectile. Targets fish within reef structure. Sometimes barbed.

Harpoon: distinguished from spear as usually wooden and lacks function as projectile – mainly used in gleaning but can target fish and octopus.

Speargun: usually home-made with a wooden grip and very basic elasticated projectile. Spears also home-made from wooden rods, often with simple barb. Fishers may dive in shallow water using locally fashioned masks and snorkels.

Hand Line: often single, weighted, monofilament looped line with one or several baited hooks. Can be operated with or without a vessel in shallow waters. May also have a 'trace' section of stronger wire to prevent loss of the hook.
*Marginal gear = longline of multiple set hooks on strong line – rare and not included in this study

Basket trap: usually hand made locally from plant material (often bamboo) with v-shaped entry hole for fish. Deployed baited in a range of habitats, often left for a few hours or overnight with a marker float.

Beach seines: very large fine-mesh nets that may be made from a wide range of scrap or bought materials (including mosquito nets). Cod end is usually of a more robust materials such as rice sacking. Deployed by multiple fishers (~10-30) from the shore (by canoe) as a seine net before being manually dragged in.

Monofilament gill net: usually stationary deployment with weight and floats from a canoe aiming to entangle fish by their gills. A wide range of lengths up to ~50m. Often set and left for a few hours or overnight. Mesh size ~2-2 ½ inches
*Marginal gear = Jarifa gill net of much thicker line and larger mesh size (2-5 inches) targeting large fish and sharks – rare and not include din this study.

Ring net: purse seine-like deployment from a larger boat with multiple fishers (~15-20). Multi-filament nets used of ~3 inches with floats, weights and a purse 'string'. Often used to target schooling fish. A more expensive gear, relatively rare.

Figure 5.1 - Predominant gears of Cabo Delgado artisanal fisheries (Hand line photo from Samoilys, Maina & Osuka, 2011, other photos by R. Short)

In this chapter I use this case study to explore the role of MNF in socio-ecological systems by providing the first in-depth look at the activity for a specific location. Central to this I aim to test to varying degrees some of the ecologically-relevant assumptions of risk that I explored in Chapter 2, which have pervaded the grey literature, media and limited peer-review literature, and which have supported actions by multiple governments (including that of Mozambique) to illegalise MNF:

- MNF threatens biodiversity through indiscriminate fishing and damage to benthic habitats.
- MNF encourages new entrants to the fishery owing to the high availability of free and/or subsidised MNs, and the limited fishing experience, capital or vessel necessary to fish using MNs.
- MNF threatens livelihoods by competing with other gears for limited fish stocks
- MNF leads to recruitment overfishing (or may pose a risk of doing so)
- MNF largely targets juveniles due to the small mesh size. This undermines the sustainability of stocks targeted by MN fishers and may lead to growth overfishing.

5.2. Methods

A mixed methods approach was taken in order to investigate the various aspects of the fishery, enabling me to address some of the difficulties in data collection highlighted above. Table 5.2 shows some of the ideal data requirements to test the aforementioned assumptions in principle, alongside the mixed method applications and adaptations that were used to overcome some of the logistical and methodological constraints of this study. It should be noted that these methods are investigative in nature. The consequent limitations on the inferences that can be drawn are addressed in the discussion. Data collection was performed by a mixture of the author and in-country staff, largely dependent on local logistical and cultural conditions. Data was collected from all six OSOL sites. Site characterisation interviews were conducted with the leaders of each site prior to the start of the study, revealing strong similarities in fishing gears used and some shared fishing grounds. Whilst cultural and physical differences do exist between sites which may influence the fisheries (with key differences explored in Chapter 6), for the purposes of this chapter, information was pooled for analysis to give a broad overview of the region.

Table 5.2 - Ideal methods and data for testing of assumptions and how a mixed methods approach was applied to tackle logistical challenges in this study.

Assumption	Assessment needs (ideal)	Adapted mixed methods (actual)
A - MNF threatens biodiversity	• Detailed time series of habitat health assessments in fished and unfished sites using benthic transects. • Fisher follows with documentation of damage. • Detailed mapping of fishing grounds with ground-truthing of habitat types in fishing zones performed. • Full composition breakdown from structured fisheries sampling informs ecosystem models.	• FGDs explored deployment methods, adaptations to nets, changes over time, and gender differences alongside fisher perceptions of gear use causing benthic damage. • A rapid assessment of all gears' catch composition was carried out between Sep-Dec 2016 giving species richness and average trophic levels by gear type to infer differing potential for risk on important functional groups. This was the first time MNs had been included in landings data. • Participatory mapping aimed to elucidate habitat use for different gears and deployment types.
B - MNF encourages new entrants	• Time series of no. of fishers utilising each gear type e.g. from licensing data or long term landings monitoring with standardised sampling. • Time-series of MN distribution by village. • Time-series of occupations and previous locations of residents and fishers. • Assessment of fisher's gear diversification (to or from MNF) e.g. using licensing data, alongside demographic change at each village.	• Timeline Focus Group Discussions (FGDs) qualitatively explored changes in gear use and engagement with the fishery by new fishers over time according to fishers' memories.
C - MNF poses a risk of recruitment over-fishing	• Time series of landings data for all gears from before inception of MNF and for several years thereafter (or at least several years to account for variability), ideally with equivalent datasets	• A rapid assessment of all gears' CPUE was carried out between Sep-Dec 2016. • Timeline FGDs explored changes in catch sizes for MNF target species for a preliminary look at risk to the fishery.

	for suitable matched control sites without MNFs. • Catch per unit effort (CPUE) monitoring over time.	• Catch relative abundances are calculated for predominant species to assess actual offtake by gear. Comparisons of risk are made between gears but empirical assertions on current and future impacts are not possible. • Recruitment fishing is not empirically tested, but variability of risk across gears is explored.
D – MNF competes with other gears	• Compositional breakdown of species landings for all gears over time, again with matched controls where possible, informs ecosystem model where scenarios of gear use can be tested.	• FGDs explored conflicts between fishers and gear types. • Catch landed weight for predominant species is calculated to assess overlap between gears. • Trophic level averages and ranges further demonstrate overlap between gears.
E - MNF catches mainly juveniles	• Landings data for all gears including representative monitoring of maturity when assessing composition.	• Alongside compositional landings data, a focused rapid assessment uses sampled total length data from individuals caught using intertidal MNF methods to assess juvenile composition using length at first maturity information.

5.2.1. Focus groups

Focus group discussions (FGDs) were conducted at all sites in March 2015 (Nsangue Ponta, Quifuque, Lalane) and November/December 2015 (Quiwia, Quirinde, Malinde, Lalane) with gender disaggregated groups, save for Malinde where a mixed FGD was held at the request of the CCP leader. Translation from Kimwani to English was performed by local staff, except in the case of one FDG in Lalane which was conducted in Kiswahili by a member of CORDIO staff from Kenya. A detailed protocol, alongside a briefing, was provided to translators prior to meetings (see Appendix C.2). Neutral, community areas were used for FGDs, with soft drinks provided to attendees. In three villages (Lalane, Quiwia and Malinde) a male 'chaperone' was required for female FGDs; these chaperones were instructed not to influence the group by interjecting. A total of 37 women and 22 men were actively involved in FDGs, all of whom were selected by local staff prior to meetings for knowledge of MNF activities. Meetings focused on the physical and economic characteristics of MNF.

5.2.2. Participatory mapping

Mapping exercises were conducted with fishers of each community in order to identify predominant fishing zones. A focus was put on identifying intertidal, reef and subtidal zones, alongside predominant gear use and species availability in each. Groups of fishers were predominantly male, however I ensured that at least one female fisher was present for each mapping exercise. Maps were drawn freehand by in-country staff, using google maps images as a guide. Local landmarks such as important buildings, infrastructure (e.g. telephone masts), offshore islands and tidal currents were used to orient fishers. Fishers discussed fishing zones until coming to a consensus, fishing ground names were then cross-referenced with existing landing site data to ensure all were accounted for. Any later discrepancies were clarified using focus groups.

5.2.3. Timelines

Timeline FGDs were held with female MN fishers in the villages of Quirinde and Malinde, as these villages were the focus for socio-economic investigations (Chapter 6). Recruitment for timeline exercises focused on obtaining a range of ages and fishing experience. Fishers were first oriented to the timelines by identifying temporal landmarks by using topics of discussion such as local history, Mozambican political history, memorable events such as food shortages and flooding, arrival of NGOs and industry (oil and gas). In both FGDs the starting point was chosen as independence from Portugal, and each FGD had at least one attendee who had a personal memory of this. Fishers were then asked to discuss and describe memorable changes in a) numbers of people using MNs to fish and b) relative size of fish catches. Additional qualitative information not necessarily relevant to the temporal analysis was recorded and was analysed alongside the general FGD data.

5.2.4. Landings data collection (rapid assessment)

Landings data were collected by village technicians employed as part of the OSOL project between the start of September and end of December 2016 as part of an intensive catch assessment. Surveys were conducted weekly during neap tides and twice-weekly during spring tides due to increased fishing activity at these times. During each survey, landing sites and beaches were roamed by technicians trained in fish identification and all fishers returning to the site were surveyed upon arrival. It should be noted that although efforts were made by technicians to comprehensively sample fishers on a given day, sampling for a minimum of 4 hours, defined landing sites are not always a feature of these areas, nor are they a necessary stopping point for all fishers. We cannot therefore draw conclusions as to total fishing intensity. Technicians recorded total catch weight and total species weights once catches had been separated.

Species identification was conducted in-situ. Due to capacity concerns, and because for all project uses of the data fish were deemed a priority, Crustacea and molluscs were not included in I.D. and therefore were excluded from further analysis at this level. It should be noted that, from the author's perspective based on wider observation, despite shrimp being perceived as important broadly in chapter 4, catches in the Cabo Delgado fishery were not as significant as expected. Where I.D. was uncertain, photographs were taken and local names recorded for later identification from guides and a database of local names. In the case of large catches or those with numerous individuals, a subsample was taken for composition measurements and extrapolated to the whole catch. Abundance was also recorded for each species, either from total catch or subsamples. Where individuals were too numerous to count even from subsamples (MN catches in particular can contain very large numbers of individuals and can be subject to monitoring time constraints) abundance was calculated by taking an average weight of the relevant species for the relevant gear and dividing the total species weight by this value. This was deemed the most robust estimate of abundance, compared to the alternative of visual estimates (multiple data collectors meant that this method would be unreliable). Number of fishers, sex of fishers, time fishing (start and end), gear type, vessel type and fishing ground were recorded based on information from fishers.

5.2.5. Targeted mosquito net and juvenile composition surveys

Additional landing site data was recorded specifically for female MN fishers by the author and a dedicated member of in-country staff. Data collection followed the same protocol as the broad landing site data collection in order to remain comparable, however juvenile composition was additionally assessed. Following composition analysis, up to 10 randomly selected individuals of each species were measured for their total length, in order to assess maturity status by comparing with length at first maturity estimates. Data was collected between January 2016 and April 2017.

Extension of these surveys to male fishers was largely not possible due to the taboo on the activity, the influence of the author's presence and the female gender of the in-country staff member. Composition data for this gear type was collected following trust-building and normalisation activities by village technicians (who live onsite), as part of the overarching landing site surveys which was overseen by the project Marine biologist.

5.2.6. Analyses

Length at first maturity (Lm), length-weight relationship co-efficients ($W = aL^b$) and trophic level (TL) data were obtained from FishBase for the species recorded. Lm values from *Spratelloides delicatulus* were used to generalise Clupidae maturity and both Clupidae and Engrualidae TL values, as these were not generally identified to species level but this species was regularly seen in catches of the relevant

gears. Trophic levels per catch event were calculated by weighting TL by abundance of relevant species and obtaining the mean across these species.

Catch per unit effort (CPUE) was calculated for each catch event, as catch per fisher, per hour. The use of a per hour effort measure was to account for highly variable fishing times, particularly between men and women, allowing an estimate of soak time for comparison of gear efficiency.

Differences in both CPUE and TL between gears were analysed using Generalised Linear Models (GLMs) owing to the non-normal distributions of the data.

Shannon-Wiener (H) and Simpson's (D) diversity indices were calculated for each gear using the following formulae:

$H' = -\sum_{i=1}^{s} p_i \, ln(p_i)$ where p_i = proportion of s made up of the i^{th} species, and s = the species count

$D = 1 - \sum {p_i}^2$ where p is the proportion of individuals of each species, divided by the number of individuals in the sample.

Species accumulation curves were calculated to show the species richness of each gear as the number of catch events increased.

'Top 20' species across gears were calculated by weighting each species count (for abundance) or biomass (for landed weight) from each gear by the number of instances of use of that gear and summing across the species before ranking by the summed values.

Species representing 80% of catch for each gear were defined by calculating each species' proportion of individuals for each gear (for abundance), or proportion of total biomass for each gear (for landed weight) before ranking and selecting those summing to 0.8 of the catch.

Statistical analyses were performed using R 3.5.0 (R Core Team, 2014).

5.3. Results & Discussion

In this chapter I provide both an in-depth characterisation of a MN fishery for the first time, in order to expand our knowledge of how MNF gears fit into the broader fishery, and also use empirical data to test the validity of various assumptions that have led to restrictions on MN use in many fisheries. Whilst the chapter responds to the need for more localised context and case studies (particularly in the marine realm) to enhance understanding of MNF and begin to challenge these assumptions (Chapter 4), the lessons learned are likely to be widely applicable throughout East Africa (Bush *et al.*,

2016). Indeed in terms of the need to challenge current paradigms and for promotion of evidence-based policies and approaches to fisheries management, I believe the issues discussed below are of relevance to all areas globally where MNF policy is necessary.

Characterising MNF: Kutanda vs. Chicocota

Focus group discussions, observations and participatory mapping with both men and women revealed a distinction between two main modes of deployment for MNF, with associated habitat preference, gender divisions and potential for conflict that are of relevance to all other results. These methods are detailed below prior to additional results and hereafter I will distinguish between these two methods as Kutanda and Chicocota; references to MNF will be used only for results that do not differ depending on the method of deployment of MNs.

'Kutanda'

The word Kutanda relates to a traditional form of fishing mainly conducted by women, and traditionally using cloth such as 'Kapulana' wrap-around skirts, but which is now regularly used to describe the predominantly female form of MNF. More broadly throughout East Africa this practice may also be referred to as 'Tandilo' fishing (Bush *et al.*, 2016). Women show a preference for utilising shallow water habitats which is likely related to their swimming ability and restrictions of social norms. Whilst mangroves may have once been a preferred location for Kutanda, since the advent of MNF, sand flats and thin seagrass have been described as the preferred habitats for Kutanda. This change in location is reportedly related to both: a) a need for wider, open spaces as several MNs (typically between 3 and 7) are sewn together to form a seine net, and b) a desire to avoid habitats where the nets may snag and tear, including thick seagrass which hides sharp bivalves (such as pen shells) and rocks. Many of the OSOL sites are characterised by narrow, sparse patches of mangrove and these may still be used for Kutanda. Coral reefs were specifically cited as avoided, however some fishers said they may use the edge of the reef and rocky areas where visibility is good.

MNs are opened lengthways and stitched together at the ends using fishing line or thread. Some nets may be adapted to seine netting by attaching floats to the top, usually discarded flip flops, and weights to the bottom, usually gastropod shells. Typically, women reported fishing in groups of three or four in waist to chest-deep water. The combined nets are stretched between two individuals who may attach the bottom edge to a foot or toe and hold the upper edge just out of the water, slowly dragging the net as a seine. The other one or two people will walk a gradually enclosing semi-circle towards the net, splashing the water with their hands or using bowls – this job is sometimes also performed by children. The fish are herded into the seine net, which is gathered by all fishers and the catch sorted in-situ into containers carried on the heads of the splashing fishers. Few species are discarded – mainly

pufferfish and juvenile Striped catfish. Fishers reported that fishing trips were usually between 1-3 hrs. This method may also be referred to as 'Sufria'.

Figure 5.2 - Example of women fishing with the Kutanda method. Nets may be sewn together but are otherwise unmodified. Fishers may fish in groups of three or four (with either one or two chasers) up to around waist-deep water on sand flats and seagrass beds.

Almost all focus groups at all sites indicated a preference for fishing during spring tides, though whether high or low tide was preferred depended on local conditions. Most women indicated that during spring tides, unless farming is a priority for some reason, they will fish every day. Otherwise fishing frequency was cited as ~3 days per week. Similarly all sites indicated a higher fishing frequency during the rainy season (Nov – May), citing favourable southerly 'Kusi' winds and the positive impact of higher water temperatures on populations of target species as the reason, (though these population fluxes are more likely due to increased freshwater inputs which are of particular importance for early life stages of Engraulidae and Clupidae species (Hoguane, Cuamba & Gammelsrød, 2012)). Sites with lots of agricultural activity also cited occupational conflicts as a reason for seasonal fishing preferences, needing to spend more time in the fields during certain times of year, though these timings were said

to be becoming less predictable with climatic changes. Fishing at night occurs, largely under a full moon; MN fishers did not indicate nor did I witness the use of artificial lights.

Predominant species cited as targeted with Kutanda were quite specific and mostly limited to:

- 'Sala' = *Gerres oyena*, the Common silver biddy.
- 'Mingalare' = *Hyporhampus affinis*, the Tropical halfbeak, though this name may also sometimes refer to *Strongylura incisa*, the Reef needlefish, also commonly caught.
- 'Safi' = Various species of Rabbitfish but predominantly *Siganus sutor.*
- 'Sololo' = Various species of Emperor but predominantly *Lethrinus variegatus.*
- 'Ncundadji' = Various species of Goatfish but predominantly *Parapeneus macronema.*
- 'Sardinha' = Various species of Clupidae that often aren't distinguished between.

All focus groups acknowledged that catches were predominantly of juveniles of these species. Collectively, mixed catches of small fish mainly from MNF are referred to as 'Me dada' (meaning small mixed fish), and occasionally 'Dagaa' by traders from outside the area (a name taken from Lake Victoria fisheries targeting *Rastrineobola argentea,* the Lake Victoria sardine). A commonly cited benefit of MNF is that women are able to also glean concurrently, meaning numerous species of gastropods, bivalves, cephalopods and crustaceans are also collected.

Figure 5.3 - Typical Kutanda catch comprising mostly of *G. Oyena*. This was the total catch for the day between four women in the village of Malinde.

'Chicocota'

Chicocota means simply 'to drag'. In the focus groups the term was largely used to describe a specific fishing method mostly used by men, but there is some ambiguity over the use of the name and it may be synonymous with Kutanda in some scenarios. Mukuelele was an alternative name sometimes used in the more northerly sites for this method. Whilst women were fully aware of the activity, the female focus groups yielded less detail, so the information given here mainly comes from male focus groups. Chicocota differs from Kutanda in both method and net design. The predominant differences in design are that a) the nets tend to be bigger both in terms of length and depth, requiring more MNs, and b) additional layers of netting from stronger materials are sewn on to the bottom of the net, often a layer of ~15cm of thick gill net and then ~30cm of tough fine mesh netting such as window screen material with weighted bottom edges of rocks or shells and floats on the upper edge using flip flops or plastic bottles. Chicocota may or may not have a cod end, with rice sacks a preferred material for this purpose. Additional materials may require a significant financial investment in the gear compared to Kutanda, but allows their use over both reefs and seagrass, and also in open water from boats.

Figure 5.4 - Example of male Chicocota fishing activity over the fringing reef of Lalane village. In this example two men (four total) drag each end of the enlarged, reinforced net which is floated with plastic bottles and weighted with rocks.

In deployment, fishers cited a preference for use over reefs. This may also allow concurrent use of alternative gears such as spear, spearguns and even gillnets, and reflects a tendency to use Chicocota further offshore on longer trips. The larger net, though not as large as a beach seine, requires more force for seining than Kutanda. Therefore nets have a wooden brace or loop straps that go over the shoulders, and multiple men may pull each end through the water, though most fishing parties are of 3 men (two to pull, one to collect the catch). Most fishers in focus groups acknowledged visible damage to corals being caused by Chicocota use. Buckets and/or a canoe may be towed behind for depositing catch. The use of splashing and 'chasers' to encourage fish into the net seemed ambiguous, some described it as necessary and others not. A preference for spring tides was cited by fishers, though winds were not seen as a limiting factor for Chicocota, which is engaged in year-round, and night fishing is reportedly common. Some preference was shown for fishing in the dry season for ease of drying fish. Chicocota left staked in the water, to avoid detection when not in use, was witnessed in Lalane.

Figure 5.5 - Example of a medium-size Chicocota net (top) and reinforcing done for use over reefs (below). Bottom pictures were taken from a net found staked and left at sea, presumably to avoid detection.

Catches are reportedly larger for Chicocota users, but little detail was able to be gained on target species other than shrimp, which was a predominant focus. It was acknowledged that fishing over reefs gives a broadly mixed catch of fish, around a finger long of multiple species ("too many to count, there are many we don't know the name for"). Comments on juvenile composition were sometimes ambiguous, but most agreed juveniles are common in the catch.

Figure 5.6 - Typical Chicocota catch - this was a subsample of a larger catch from the village of Malinde and contained numerous reef species

The 'Ngoe' method

An additional method identified during focus groups, used by men but cited as very rare, was targeting of Ngoe fish (Striped catfish, *Plotosus lineatus*) using encircling MNs. These nets are small, with a roughly equivalent cod end, and are deployed from a canoe specifically to catch adults of this schooling species (it must be adults due to their harmful spine which means they are discarded when caught as juveniles). The method of capture was described as opportunistic, with little knowledge of how to predict schools of Ngoe; you just "get lucky". If lucky, however, the catches can be significant; a single catch record was obtained for this method of fishing, operated by a single male fisher and consisting of 16kg of Ngoe in 5 hrs of fishing.

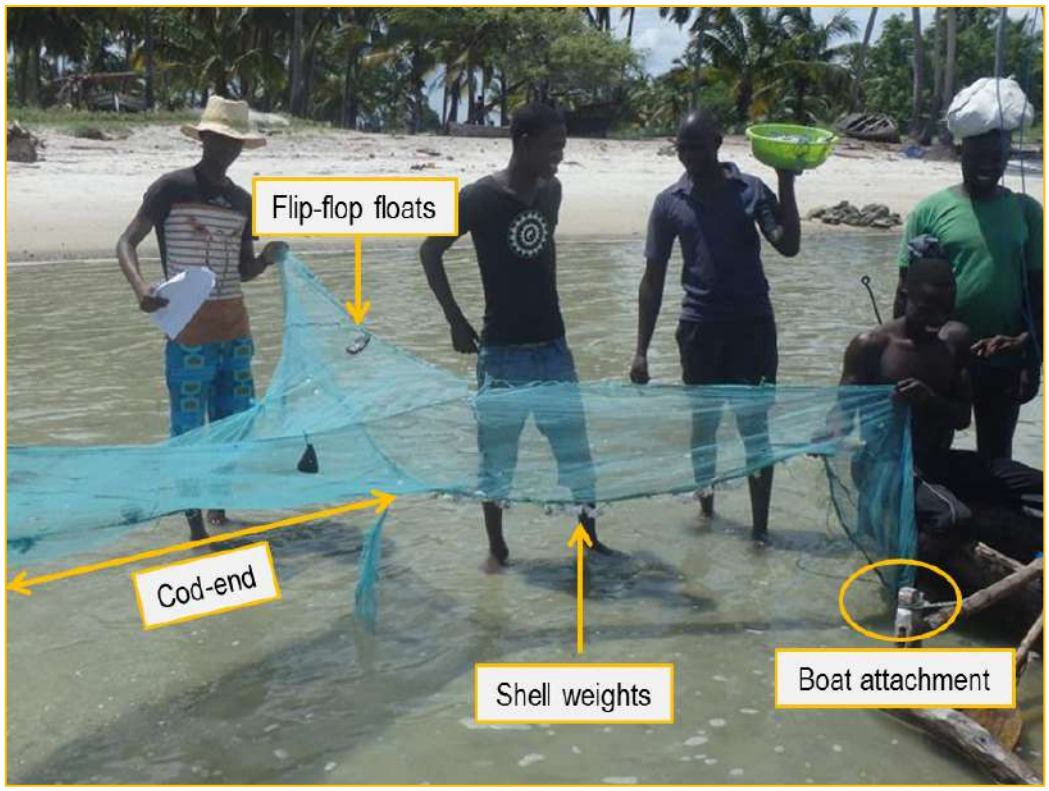


Figure 5.7 - Ngoe net following landing of catch fashioned from two to three MNs showing the cod end and attachment of the net to a canoe.

How strict is the gender divide?

It will be important for further analysis and going forward for direction of management interventions to better understand engagement rates by gender, particularly as FGDs acknowledged some engagement of women in Chicocota methods. The social norms of the region are appreciated to restrict engagement of women in fisheries, alongside time restrictions and childcare duties which impact female fishers the world over, and this restricted engagement in demonstrated in Figure 5.8 which clearly supports this theory using landings data. Here we can see women are restricted to the four gear types that are most closely associated with intertidal fisheries; a clear domination of the Kutanda method, though also some engagement in Chicocota as FGDs suggested, wide use of harpoons and limited use of spears. All other gears were exclusively used by men.

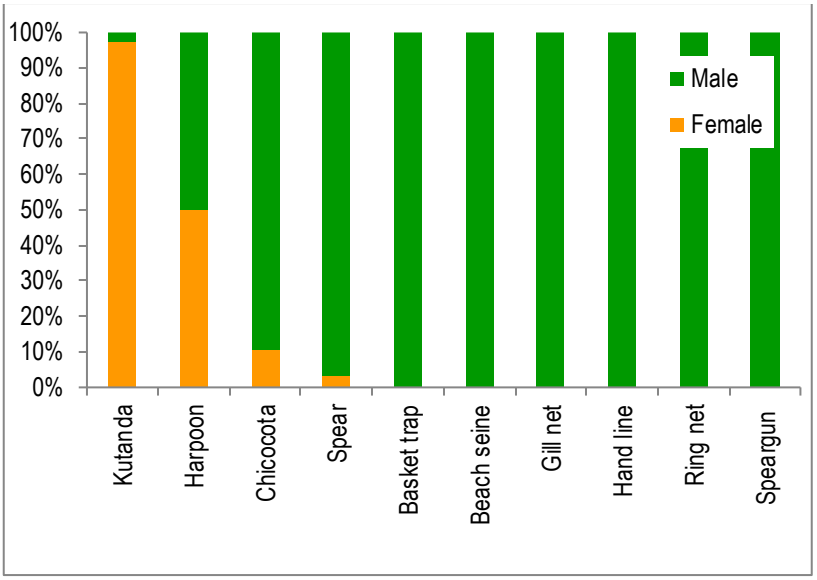


Figure 5.8 - Proportion of fishing events conducted by male and female fishers for each gear type.

Assumption A: MNF threatens biodiversity

MNF is often described in the media and grey literature as 'indiscriminate' (Figure B.2). It is therefore often perceived that MNF may be impacting widely across species and having knock-on impacts to broader biodiversity. There are legitimate concerns about ecosystem integrity, impacts on rare or threatened species and/or impacts on reef function due to depletion of functionally important species such as parrotfish. The methods described above in FGDs seem to support this description, as broad swathes of either sand/seagrass (Kutanda) or reefs (Chicocota) are essentially sieved, somewhat haphazardly, by a ~3mm mesh. Fishers also alluded to an impact of the seining method on these benthic habitats, added to increased rates of trampling in delicate areas such as seagrass beds. However, general perceptions from both men and women were of a taboo attached to Chicocota gears due to their damaging reputation, and whilst groups were concerned about the increased numbers of women engaged in Kutanda, in general this method is relatively socially acceptable. In this section I will explore the potential impacts of both types of MNF on the local biodiversity, exploring both the unselective nature and potential for physical damage.

Is MNF 'indiscriminate' compared to other gears?

A total of 238 species were recorded in the rapid assessment time period. Looking at numbers of species recorded for each gear during our survey period (Table 5.3) places Kutanda and Chicocota in the lower to middle position (7th and 4th of 10, respectively), which range from 106 spp. (gill nets) to just 3 (ring nets), though sample size for the latter was low. Despite a relatively small sample size, the highest number of species recorded per catch event was for basket traps, and again the lowest was for

ring nets. Kutanda ranks lowest of all gears at 0.8 species per sample, with Chicocota ranked in the middle at 2.07, the highest being 6.17 for basket traps.

Table 5.3 - Summary values for gear diversity comparison, with darker shading representing larger numbers.

Gear	Number of observations	No. spp. in total	Spp. per catch event	No. spp. making up 80% landed weight	No. spp. making up 80% abundance
Gill net	47	106	2.26	24	31
Speargun	43	78	1.81	17	25
Basket trap	6	37	6.17	16	16
Spear	22	53	2.41	14	17
Beach seine	23	51	2.22	10	12
Chicocota	28	58	2.07	13	5
Harpoon	5	7	1.4	13	2
Hand line	63	62	0.98	2	2
Ring net	7	3	0.43	2	2
Kutanda	60	45	0.75	1	1

Both Shannon-Wiener and Simpson's diversity indices showed a similar trend in diversity of species across gears (Figure 5.9), with the highest diversity seen in gill net catch, and the lowest in Kutanda. Again, Chicocota sits in the mid-range of this spectrum with medium-diversity catch relative to other gears and gill nets the most diverse by a large margin. Although species accumulation curves in Figure 5.10 show that these data may not have detected the full range of species for some of the gears, particularly those with low sample sizes, Kutanda shows some levelling off which indicates these results to be representative, though Chicocota species diversity may be yet higher than reported here. This suggests that Kutanda is impacting across a very narrow range of species compared to all other gears including Chicocota. This evidence does suggest that for neither of the MNF gears could one assert that it is indiscriminate compared to other gears, and that although Chicocota demonstrates a lower level of selectivity it is by no means the worst offender in the fishery as a whole.

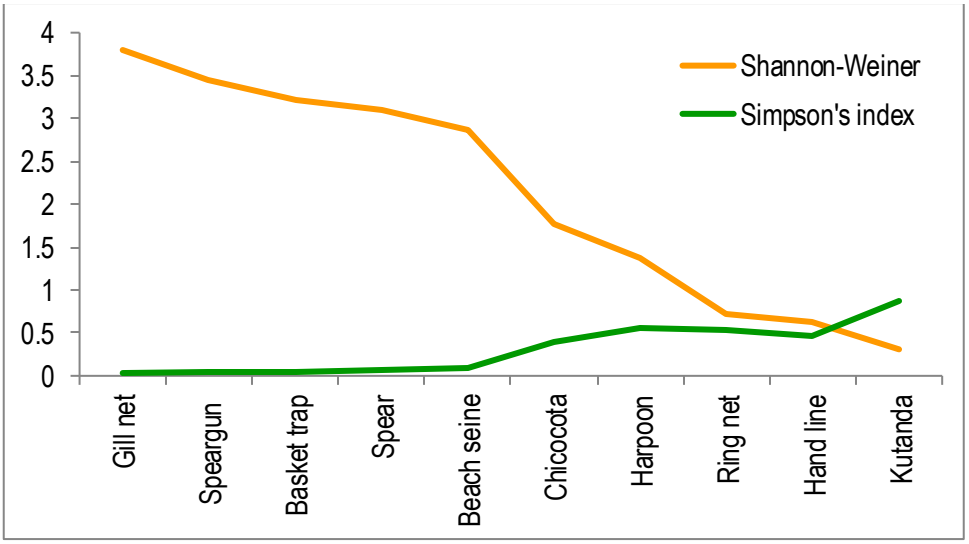


Figure 5.9 – Shannon-Weiner and Simpson diversity index values of catches across gears – gears ordered by SW value

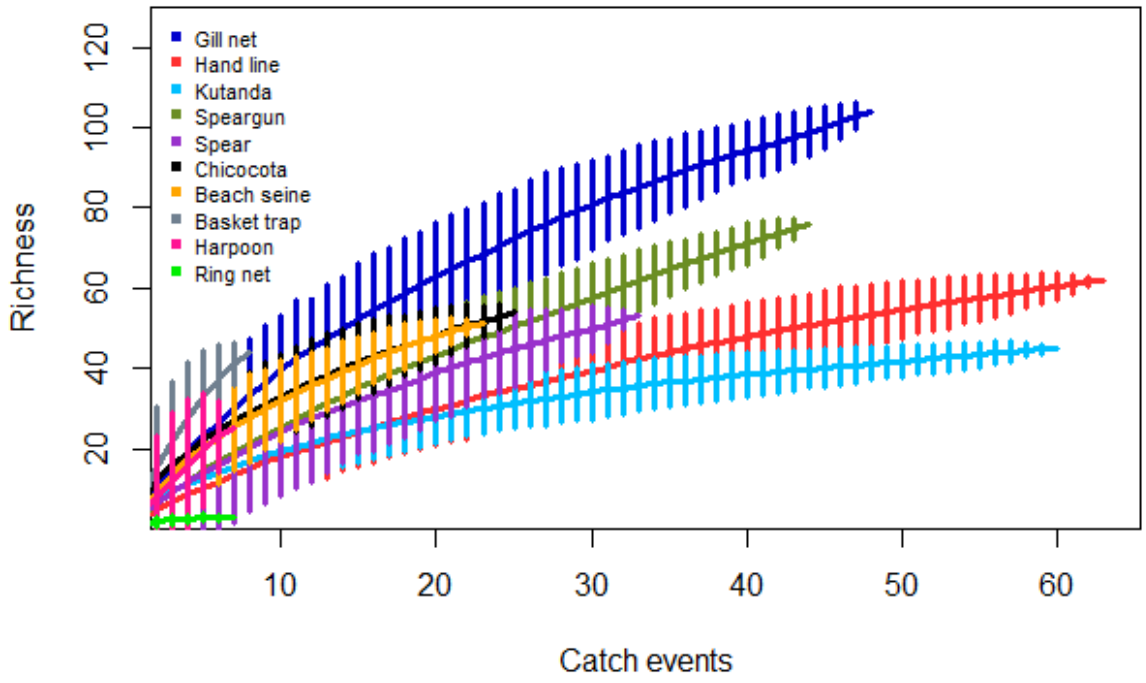


Figure 5.10 - Species accumulation curves from catch events (numbers of fishing trips) for each gear

However, species numbers are not the only consideration when assessing potential impacts to biological systems. Fishing gears may also upset diverse and dynamic systems such as coral reefs by impacting disproportionately across food webs. Commercial targeting of low Trophic Level (TL) species may often be considered less impactful due to our global tendency to target high TL, high value species and a consequent effect of 'fishing down the food web' (Pauly *et al.*, 1997). Fishing high TLs is theorised (though increasingly controversially) to have severe top-down impacts on food webs, such as meso-

predator release (Ritchie & Johnson, 2009) and trophic cascades leading to effects such as population booms of low TL grazers (e.g. Parrotfish) (Mumby *et al.*, 2012). However, grazers on coral reefs are also important for coral health, playing an important ecological role in the removal of algae and bioerosion, so overfishing low TLs can also be detrimental to biodiversity. For comparison of range and average TLs fished across gears, values were calculated for each catch event by weighting species TLs by abundance (frequency in catch). The average of these values varied significantly across the gears (Figure 5.11). The highest average trophic level was for hand line catch at 3.66, and the lowest was for kutanda at 2.85. Chicocota ranked 6th out of the 10 gears with an average TL of 3.21, representing predominately carnivorous fish. When looking at the species comprising 80% of catch for Chicocota in particular (Figure 5.17, below) it can be argued that none of those ranked highly are of particular concern in terms of their reef ecosystem impact, *Scarus ghobban* catch may be of minimal concern due to its importance to reef grazing and function but ranks very low in catch importance. Overall, both Kutanda and Chicocota are likely to be having a minimal impact in terms of TL and ecosystem function compared to most other gears (Figure 5.11).

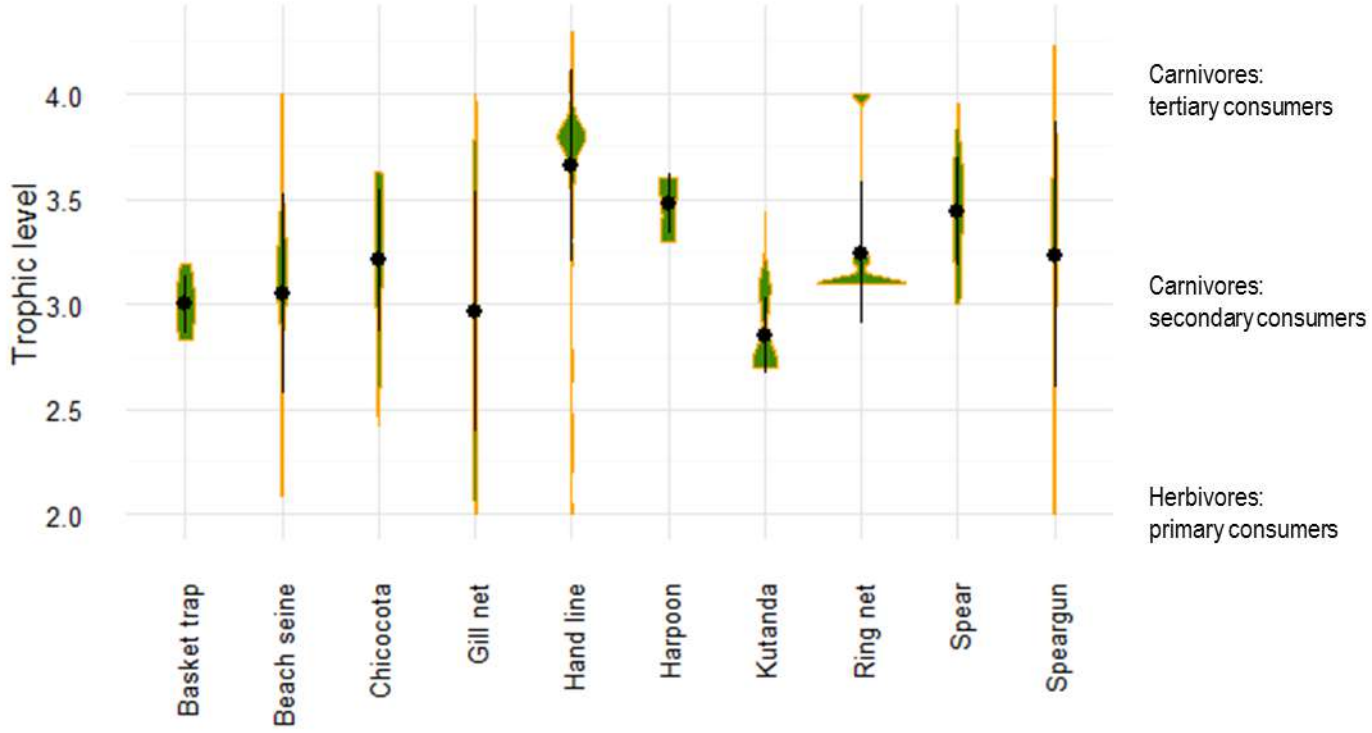


Figure 5.11 - Violin plot showing distribution of species abundance-weighted catch trophic levels across predominant gears. Black dots and lines are mean values with standard deviations. GLM of TL by gear type, Adjusted R-squared = 0.8764, F-statistic = 134.8 on 16 and 286 DF, p-value = < 0.005

Concerns were also raised in the FGDs regarding direct habitat damage that may be caused by additional trampling by fishers and seining impacts from nets, particularly in coral reef and seagrass habitats. Landings data shows fishing zone use to differ between male and female fishers and between the two deployment types. Male fishers using Chicocota reported using subtidal fishing zones and those intertidal zones with coral reefs, whereas female fishers using Kutanda reported predominant use of intertidal areas (Table 5.4). Female Chicocota use (n=2) was in intertidal zones. These results are reflected in vessel use, with the majority of female Kutanda use occurring on foot and the majority of male Chicocota use occurring by canoe. Those occurrences of motorboat use by women (n=2) both utilised Kutanda and reflect use of offshore islands.

The confirmed preference for MNF use (both deployment types) in these habitats suggests these concerns may be valid. This study is not able to fully assess the total footfall pressure of MNF, but the professed increase in numbers of fishers and shift to more open habitats (Figure 5.12) suggests damage may occur. Whilst Kutanda nets may not be responsible for much of the net damage as fishers professed to nets described for Chicocota fishing suggests that nets have been specifically adapted to avoiding difficult habitats and operating in areas where gleaning is occurring anyway, the adaptations to withstand damage from substratum impact. Physical damage to reefs requires prolonged periods of recovery and can have longstanding knock-on impacts on biodiversity. Seagrasses are particularly vulnerable to this type of damage. The huge importance of seagrass beds to fisheries, local and distant, and their use worldwide, particularly by small-scale fishers, is only recently being fully realised (Unsworth, Nordlund & Cullen-Unsworth, 2018). The seagrass beds of Cabo Delgado are demonstrably diverse and important, particularly for some of the species highlighted as important here e.g. *Siganus sutor, Leptoscarus vaigiensis, Lethrinus variegatus, Lethrinus lentjan* and *G. oyena* (Gell & Whittington, 2002). The highly connected nature of these habitats as nursery and spawning grounds means knock-on impacts are a legitimate concern (Unsworth *et al.*, 2008).

Table 5.4 - Proportion of male (n=29) and female (n=74) MNF catch events by fishing zone type (habitat) and vessel type for MNF

Fishing zone type	Proportion of female catch events	Proportion of male catch events
Intertidal	0.76	0.00
Intertidal/shallow reef & seagrass	0.16	0.34
Subtidal	0.00	0.41
Offshore island	0.07	0.17
Vessel type		
Foot	0.97	0.28
Canoe	0.00	0.62
Sail boat	0.00	0.10
Motor boat	0.03	0.00

Assumption B: MNF attracts new entrants to the fishery

The assumption that MNs, through their free availability and ease of use, may attract new entrants to the fishery is both supported by the data presented here and challenged as a potential over-simplification. Timeline FGDs with female fishers described an overall increase in numbers of people engaging in MNF over time since independence (Figure 5.12), with fishers remarking on a rapid increase since the introduction of the distribution of free nets for malaria control. Initially this led to a perceived rise in catches, owing to increased efficiency. However, fishers' perceptions were then of a rapid decrease in catches, along with a change in catch sizes resulting in what they consider to be a current crisis.

"*Last year there were no fish, we caught very little. I don't know if the size of fish has changed, only that we never catch a big fish now*." Female respondent, FGD Lalane.

This increase in MNF prevalence reportedly included a process of conversion to Kutanda from a similar method which used traditional cloth fishing gears, and uptake of Chicocota methods by local men, as opposed to just encouragement of new entrants to the fishery.

"There have always been Kutanda fishers, I can't remember when, we have fished since childhood with kapulana. Before these nets were free we could buy them from Tanzania." Female respondent, FGD Lalane

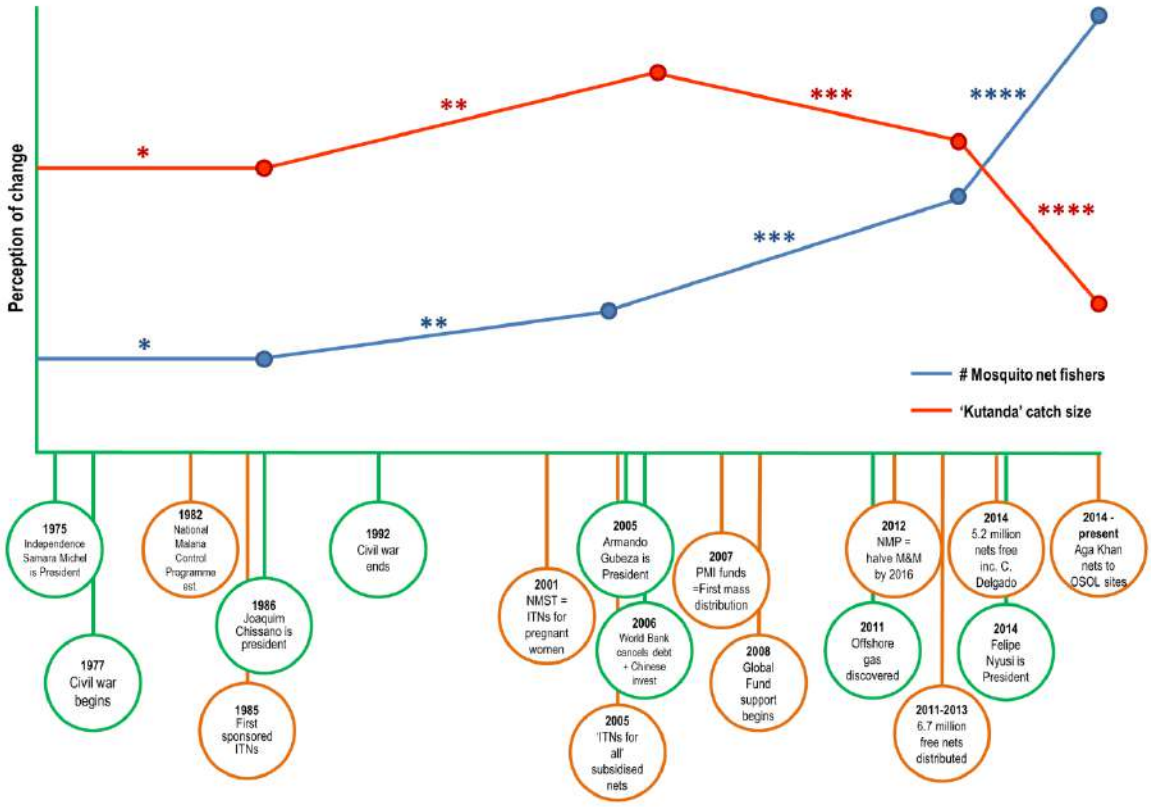
"We have too many sons. What can they do? We never ate [Moray] eel before, now we do. They didn't use Chicocota before, now they will." Female respondent, FGD Quirinde

Many of the women traditionally engage in gleaning activities in intertidal zones to which they are restricted by social norms and their swimming abilities, being largely marginalised from the wider fishery. In this case MNs, rather than necessarily encouraging new fishers, instead serve to both increase the efficiency of female fishing activities, and also to allow them access to new resources/species, as demonstrated by reports of a move from predominantly mangrove-based activities to sand flats and seagrass.

MNF is a productive gear in the context of the fishery as a whole (Samoilys *et al.*, 2018), particularly for women for whom it is particularly productive and valuable.

"Our only important [fisheries] resource is [MNF]. For us we are not so practiced at catching octopus and the crabs are not for money." Women's FGD Quirinde

Alongside the perceived declines in species traditionally targeted by 'male' gears, this is likely to be driving the rise in use of Chicocota by men expressed in FGDs, which may serve as both an effective fall-back option for existing fishers experiencing declining catches, as well as an entry point for new and inexperienced fishers.



* MNs difficult to get hold of; have to source from Tanzania. Few people MNF but some women fishing in same way, 'Kutanda', with 'Kapulanas' (cloth skirts).

** More MNs available (development projects begin) and more people fishing due to food shortages, but most people using window screen/fruit nets for Kutanda.

*** Gov. and NGO distributions start. People start to buy MNs for fishing at lower cost (25 mzn) but still a considerable barrier. First knowledge of Chicocota method (not done here). Itinerant fishers begin to use village (~2010).

**** Free MN distributions from Gov. and Aga Khan = lots of people start to MNF. Migrants increase and establish (mostly from Nampula). Chicocota starts.

* No memorable change. People fished mainly to eat and couldn't afford to buy fish. The species caught were different as the method was inefficient. Women fished mostly in the mangroves.

** Fishing became better with more efficient methods/gear, women started to sell fish at 1-5 mzn per 'portion' (handful). Fishers moved to the beach for more space; began to catch good quality catch (Up to 4 basins (~40kg) between 3-4 fishers) of species seen now (Needlefish, Silver biddies, Goatfish, Rabbitfish, Trevally).

*** Kutanda catches start to decline in yield and quality but prices increase (5-10 mzn per portion). Conflicts with migrants begin over Chicocota use (sometimes violent).

**** Rapid catch declines for Kutanda. 10 mzn per portion but ½ a basin between 4 women (~5kg). Can still catch small Silver biddies and Rabbitfish, but few Goatfish, Needlefish and Trevally. Local men begin using Chicocota, and eventually some women (very recently; 2016).

Figure 5.12 - Combined timeline FGD details from female fishers in the larger villages of Malinde and Quirinde

For already time-poor women, trading off household duties alongside those of agriculture and daily food needs, MNF may become increasingly important as an activity which can fit in with other commitments, particularly farming, requiring just a few hours of a day to provide a meal; average fishing time for Kutanda was 3hrs and 44 minutes (S.E. +/- 6 minutes). Additionally, agricultural decline is increasing the importance of fisheries, particularly for the time-poor. This has a bearing not only on the intensity of fishing by individuals, but also the numbers of people fishing. Samoilys *et al.*, (In Press) have shown that across the six OSOL sites mosquito nets are now the most commonly used gear (Figure C.5) supporting the perceptions presented here of a rapid increase, though a lack of baseline information means we cannot quantitatively infer how long this has been the case or how quickly it has occurred. This high level of engagement in MNF from both sexes, which is highly likely to include use by new entrants, has likely driven the perceived increase in local pressure on this mixed fishery. Fishers perceived declining Kutanda catches in Cabo Delgado (Figure 5.12). Unfortunately the snapshot data presented here are unable to empirically explore these perceptions any further. There may be an impact of Chicocota at play, or the perceptions may be the result of an illusion of declining catches as numbers of fishers increase and catches are shared more widely, or indeed may represent a detrimental impact of unsustainable levels of effort and/or juvenile capture that counter the inferences made here.

The overall increase in numbers of people engaged in MNF was also in part attributed to a rapid rise in migrant fishers (Figure 5.12), who were blamed by resident populations for the introduction of the Chicocota method. However, it is also suggested that these migrants are resented for their use of 'better' gears (owing to access to capital for gear purchase), meaning larger catches, which could discourage MN use. Whilst I personally never saw any evidence of MNF by migrants at OSOL sites, such as gears drying in the segregated migrant camps (save for on the island of Quifuque where the majority of the population are itinerant), it was commonly thought that women accompanying their husbands on these trips regularly MN fished.

Assumption C: MNF poses a significant risk of recruitment overfishing

MNF is assumed to be unsustainable due to its contribution to recruitment overfishing, whereby numbers of individuals fished are so high as to limit subsequent recruitment to target populations, which is often a function of both total fishing pressure and gear selectivity (Sissenwine & Shepherd, 1987). In exploring assumption B I have already made some investigation into overall fishing pressure in terms of numbers of fishers, and the role of MNF. This gives us insightful but limited information on what risks the fishery may face, but without a full stock assessment and time series data we cannot quantify the potential for MNF to contribute to recruitment overfishing. However, using a rapid assessment snapshot I will contextualise the potential risks of MNF relative to other, legal gears (in this

context) by exploring both catch per unit effort (CPUE), allowing another insight in to overall pressure, though it should be noted that this does not assess the overall recruitment fishing potential of MNF and remains a comparison. Additionally, I assess actual offtake by looking at numbers of individuals caught (relative abundance). Gleaning is included in CPUE comparisons but for relative abundance is excluded, only gears predominantly targeting fish (including Chondrichthyans) were included in these analyses (Figure 5.1).

CPUE differed significantly across the predominant gear types, (Figure 5.13). Speargun had the highest mean CPUE at 1.9kg (S.E. +/- 0.29) per fisher per hour, and Kutanda the lowest at 0.55kg (S.E. +/- 0.27) per fisher per hour, though this differed only marginally from beach seines at 0.61kg (S.E. +/- 1.91) per fisher per hour. Chicocota had an average CPUE of 1.1kg (S.E. +/- 0.48) per fisher per hour, ranking 6th of 11 gear types and having a similar impact as gill nets and hand lines. Indeed, CPUE values for Chicocota are comparable to those of most other traditionally male gears (Figure 5.13) alluding to a comparable impact across these gears, however once again we can see that Kutanda has limited comparable impact.

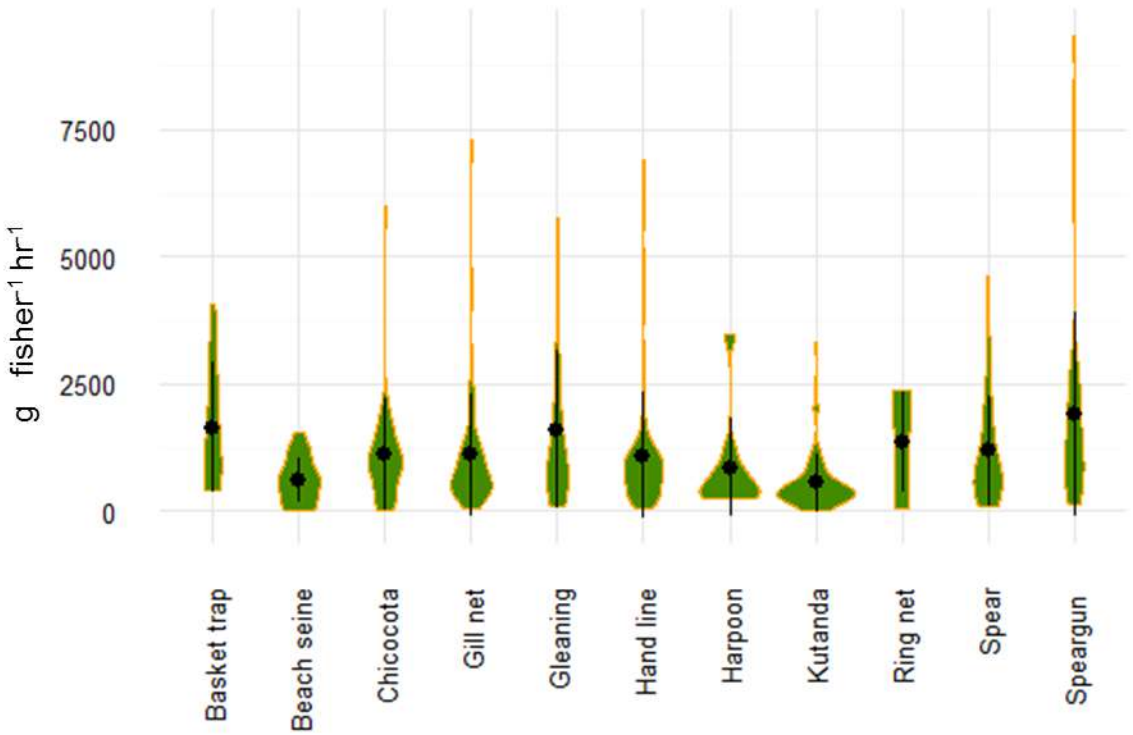


Figure 5.13 - Violin plot showing distribution of cpue values across predominant gears. Black dots and lines are mean values with standard deviations. GLM comparing cpue between gear types: Adjusted R-squared = 1, F-statistic = 8.313e+12 on 10 and 370 DF, p-value = < 0.005

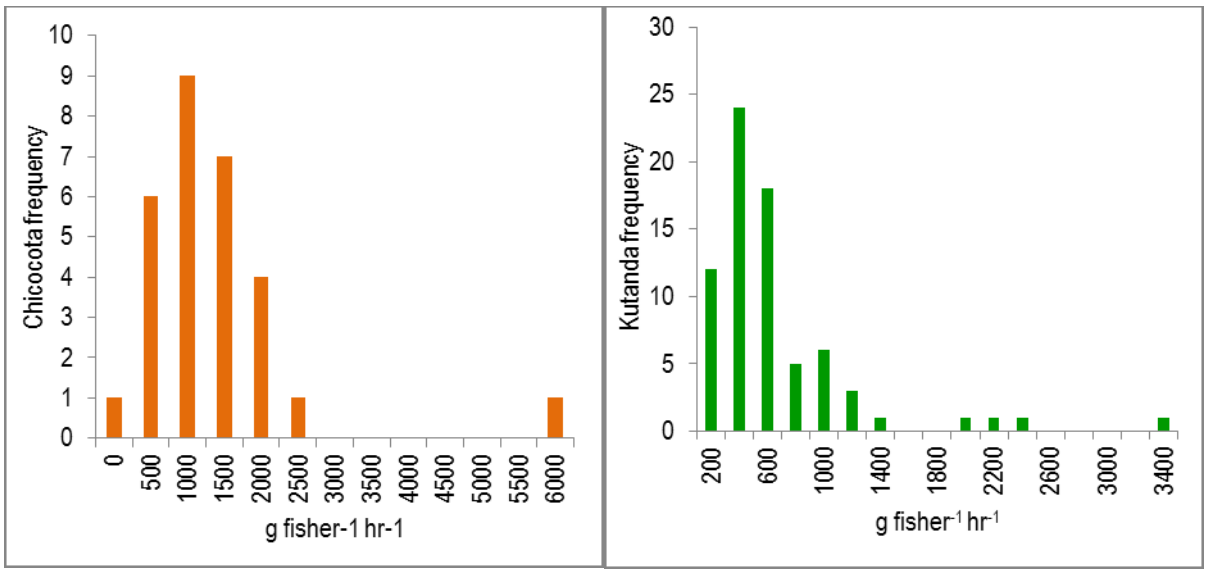


Figure 5.14 - Histograms of cpue values for Chicocota and Kutanda

It can also be noted that gender-based distinctions in CPUE extend beyond MNF deployment types, with female fishers still catching fewer fish than male fishers when using Chicocota (Figure 5.15), which may be a reflection on both the spectrum of adaptations that may delineate a Chicocota from a Kutanda net (and therefore an impact on relative effort), and also the fishing zones used. Low male Kutanda catches, mindful of the very low sample size (n=2) may support focus group indications that this method is only used by elderly or disabled males and children.

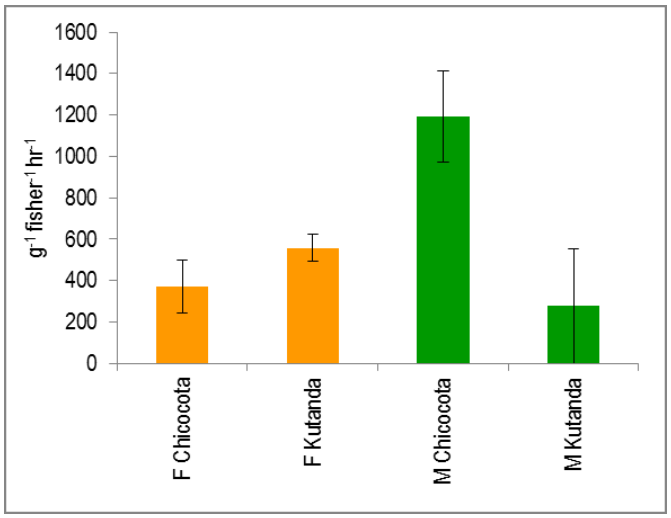


Figure 5.15 - Average cpue for different mosquito net deployment methods by gender of fishers

Figure 5.16 shows the top 20 species across all catch, ranked by abundance (number of individuals) and the contribution of each gear towards total offtake, weighted by sample size. Species are a mixture of reef and pelagic-associated species, though it should be noted that 84.1% of the total individuals were *G. oyena*, followed by 5% Clupidae, the remaining species each comprised ≤ 1% of individuals.

There are clear but segregated contributions of Kutanda and Chicocota gears to relative abundance, with high numbers of individuals caught by both gears. This is particularly true of Chicocota which dominates capture of 15 of the 20 species, indicating a broad reach across species. The high catch of *Sillago sihama* (Silver sillago), exclusively from Kutanda, is enough to place this species within the top 20, and the high relative catch of Kutanda of *Gerres oyena* (the most abundant species in the overall catch by a large margin) is marked. Catches are overall clearly dominated by small-bodied species (Clupidae and Engraulidae) and individuals (juvenile *G. oyena*).

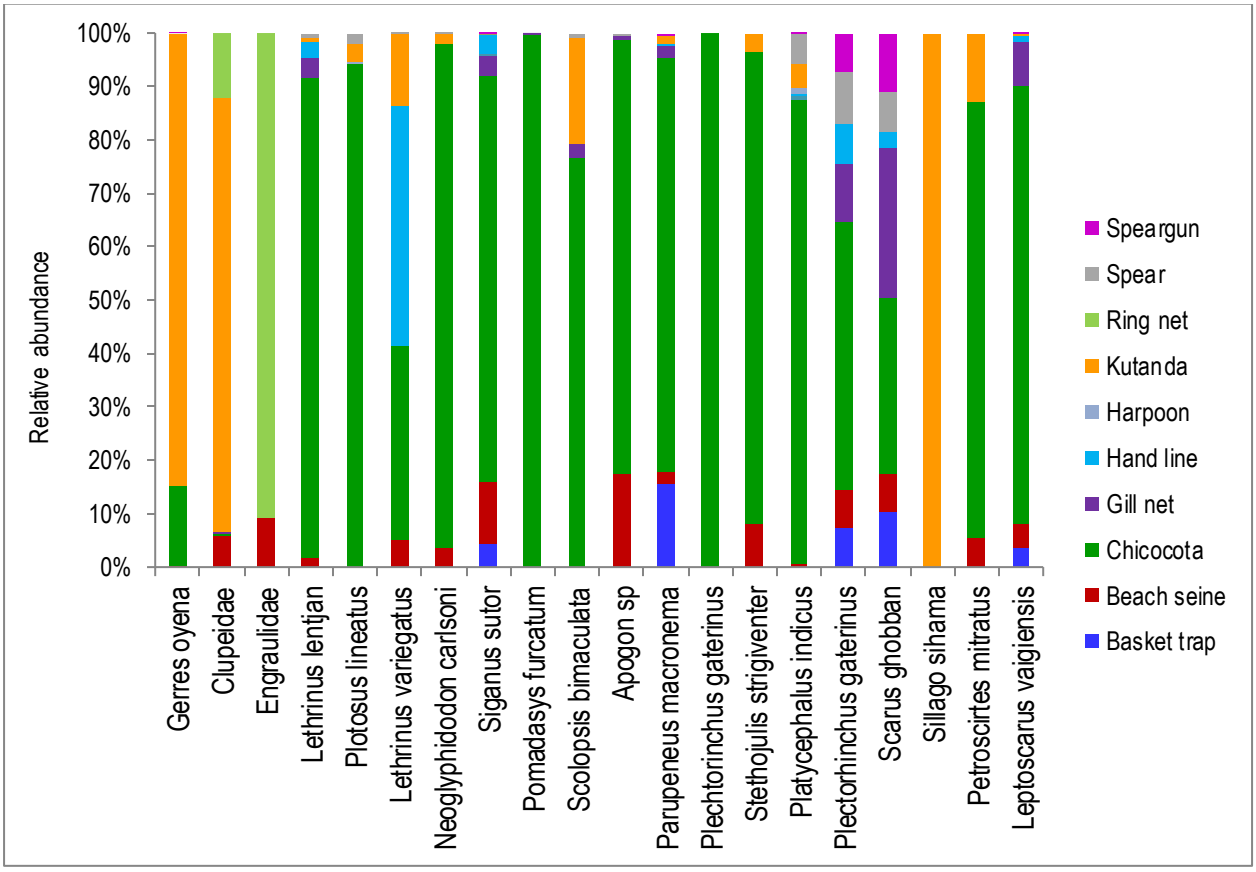


Figure 5.16 - The top 20 species (ranked left to right) by relative abundance and the proportional representation of each gear in the catch for each species

Given the reports of capture of predominantly small bodied individuals using MNF methods, coupled with the comparable CPUE (in kg) of Chicocota with most other gears it is logical that this gear would catch a large number of individuals, though the level to which Chicocota dominates capture of the Top 20 species is perhaps surprising. It can therefore be said that, at least compared with other gears, Chicocota appears to be having the greatest potential impact on risk of recruitment fishing at the level of the species presented here. This constitutes a risk to the wider fishery. Several species highlighted as important to Chicocota (Figure 5.17) may be somewhat vulnerable to excessive juvenile and/or adult capture, such as *Pomadasys furcatus* and *Papiloculiceps longiceps* which, though of medium resilience

to fishing according to FishBase scores, are listed as of moderate to high vulnerability to extinction. Whilst this is not proof of overfishing in Cabo Delgado, as further assessment would be necessary, it does seem to support concerns that, for some deployment methods at least, MNF prevents a risk to fish recruitment levels.

Kutanda, however, despite showing a similar impact on three of these species, does not seem to impact more widely, and in particular does not seem to compete with other gears. Indeed, one of these species is only targeted by Kutanda. Even when considering the high number of *G. oyena* in

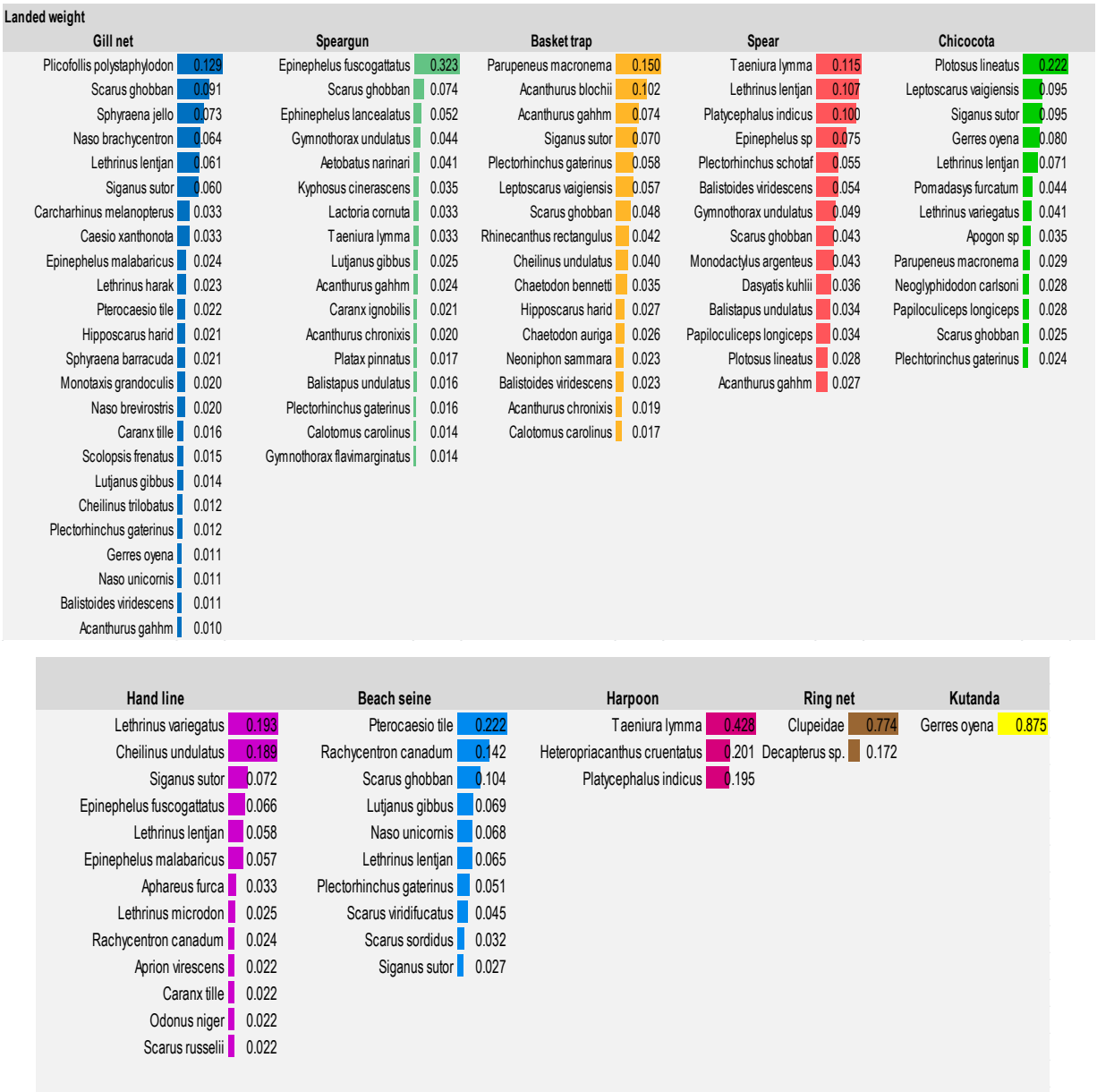


Figure 5.17 - Species making up 80% of catch once ranked by landed weight for each gear. Gears are ordered dependent on the number of species.

catches, this is a highly productive species with an estimated population doubling time of less than 15 months, predicted to have high resilience to fishing and low vulnerability to extinction (using FishBase estimates, Froese & Pauly, 2018, which are seen as more robust than Red List estimates (Strona, 2014). Arguments could therefore be made that with the estimated levels of Kutanda effort it is unlikely that recruitment rates are greatly impacted for the species. Indeed, it should be noted that of all the species highlighted in Kutanda and Chicocota catches, none are listed as of low resilience (Figure C.4). Compare this to other more targeted gears, such as spear guns and hand lines. These gears target large but few individuals and may cause impact due to their focus on BOFFFs (Big, Old, Fat, Fecund, Females). Given the increasing pressure on the fishery, this may lead to the conclusion that, although MNF presents a risk in terms of offtake numbers, it may still constitute a lesser impact on recruitment levels than some legal gears targeting fertile adults (Barneche *et al.*, 2018).

Assumption D: MNF competes with other gears for fish.

The assumption of negative impacts of MNF on the catch sizes of the wider fishery is grounded in the underlying assumption that MNF is indiscriminate, which we have already challenged in this case study, and that it catches species of importance to other gears (McLean *et al.*, 2014), which Figure 5.16 preliminarily suggests may not necessarily be the case. Here I address this latter assumption in more depth for Cabo Delgado fisheries, and additionally demonstrate further implications of gender segregation on potential MNF impacts.

Does MNF compete with other gears for species of importance?

In this section I explore the particular species of importance across the predominant gears of the fishery (again, with gleaning omitted). In order to provide insights on actual competitive power, I will present data on total species landed weight rather than numbers, as this is what determines profitability or subsistence value.

When looking at the top 20 species by landed weight, both the species present and relative contributions by gear are markedly different from relative abundance (Figure 5.18). *G. oyena* from Kutanda catch still dominates, however the dominating influence of Chicocota catch reduces, only forming a significant part of the landed biomass of *Plotosus lineatus* (Striped catfish or Ngoe) for which there appears little competition from other gears, and *Leptoscarus vaigensis* where it competes mostly with basket traps; a marginal gear in Cabo Delgado. The importance of gill nets, hand lines, spear guns and beach seines is made clear in this figure, aligning with CPUE results in Figure 5.15 and suggesting that catches of these species are not adversely impacted by MNF methods. Unlike for relative abundance, there is an influence of larger bodied species such as *Epinephelus fuscogattus* (brown-marbled grouper) and *Taeniura lymma* (Bluespotted ribbontail ray), which contribute more in terms

of wet weight than numbers of individuals. This perspective on access to fisheries resources presents the fishery as a relatively balanced, mixed fishery.

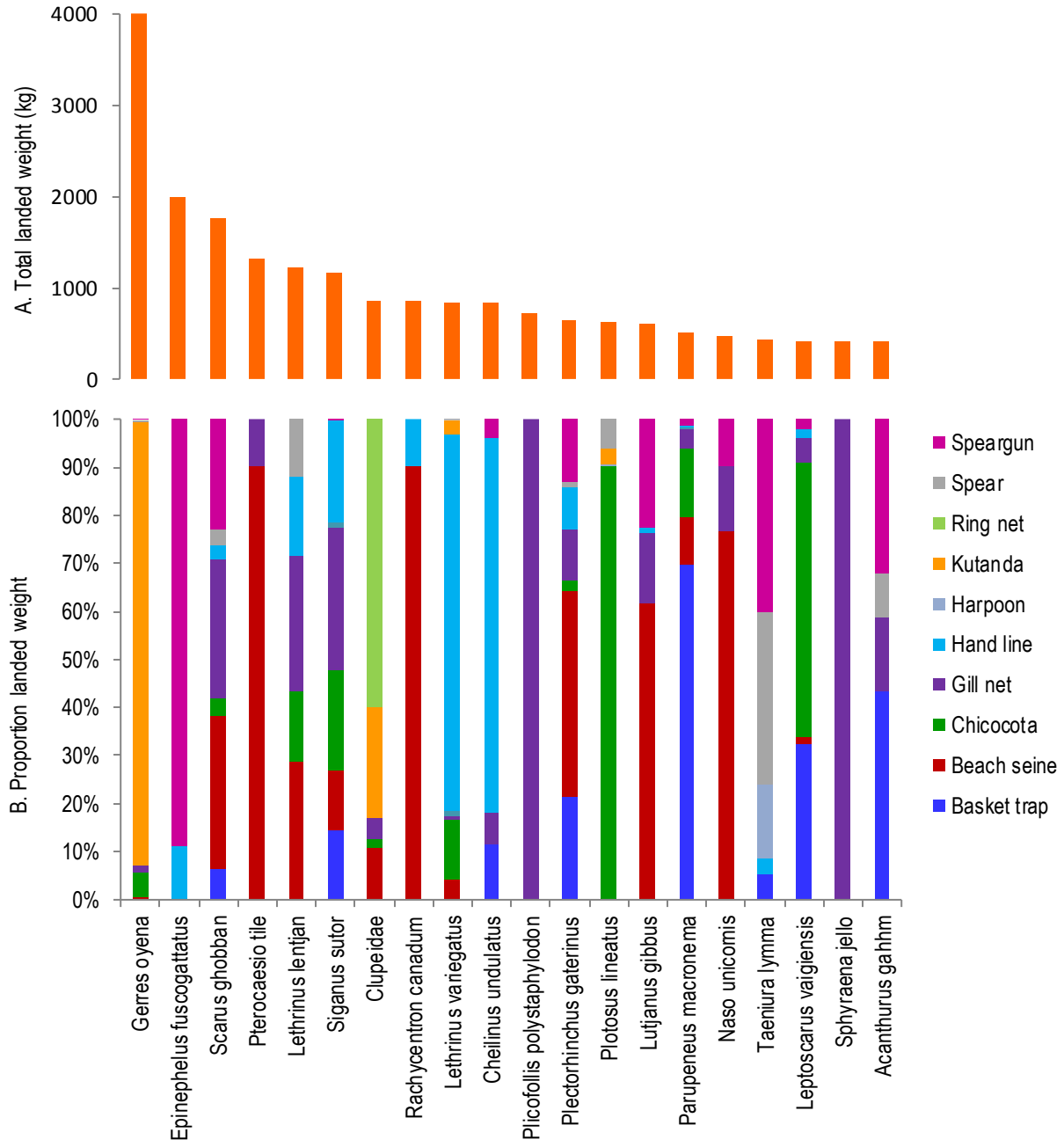


Figure 5.18 - The top 20 species (ranked left to right) by landed weight in A) the overall catch and B) the proportional representation by each gear

Species which may need further investigation because of their Chicocota catch and importance to the wider fishery include; *Leptoscarus vaigiensis, Siganus sutor, Lehtrinus lentjan* & *variegatus* (Figure C.4). These are commercially important species for local male fishers. It had been previous expected that beach seines might show a tighter species overlap with both Kutanda and Chicocota, as they

demonstrably show weak selectivity in other, similar fisheries (Gell & Whittington, 2002), however from these data this does not appear to be the case, and indeed species accumulation curves (Figure 5.10) show beach seines to catch relatively few species in these systems. However, it is worth considering research from Kenya which has shown that, in a management implementation and recovery scenario where beach seines are restricted, species overlaps in recovering catches may show a weaker relationship than fish size (size-selectivity) overlaps between beach seines and other gears (Mcclanahan & Hicks, 2011). This could have important implications for management of MNF and would need further investigation, though it is worth nothing that in the OSOL target villages beach seines are only regularly used in a single village (Nsangue ponta).

Does MNF overlap significantly with other gears in exploited trophic levels?

In considering overall fisheries management, particularly if under a BH-focused goal, it is important to ensure a spreading of different gear efforts across resource availability. As previously mentioned, commercial fishing and the governing market forces may skew efforts towards higher TL species which may be more desirable and valuable. Whilst this effect may be reduced in an artisanal fishery scenario, it warrants consideration. Looking back to Figure 5.11 clearly demonstrates a generalised spread across TLs throughout the gear range, with the exceptions of Basket traps and Spearguns which are quite specialised. Kutanda also appears to be targeting specific TLs more than Chicocota, though this perhaps fits within the bigger picture of the fishery.

In comparing the two MNF methods further, histograms of weighted trophic levels for the two mosquito net gears (Figure 5.19) show variability across the range for Chicocota, although a tendency towards increased frequency at secondary consumer levels, and a somewhat bimodal distribution of Kutanda TLs between primary and secondary consumers. The relatively low and consistent average TL in Kutanda catches may be a double-edged sword (Figure 5.11). In the case of Kutanda and the domination of catch by *G. oyena*, which has a TL of 2.7 but is a carnivore (Figure C.4), this is unlikely to be a significant concern. Chicocota exploits a much wider range and higher average TL and therefore may constitute a higher risk to other gears.

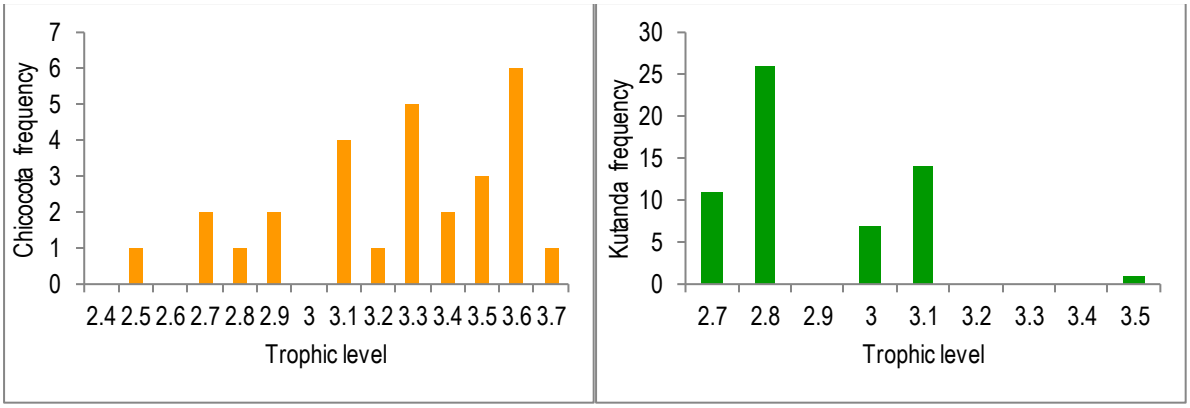


Figure 5.19 - Histogram of species abundance-weighted trophic levels in a given catch for Chicocota and Kutanda, where 2 = primary consumers and 3+ = carnivores.

Does MNF compete with other gears for fishing grounds?

In terms of the areas exploited by MN gears, and therefore potential impacts and competition for space at the highly localised level, the data for this case study again question the assumed impact of MN gears on the wider fishery. Participatory maps for all sites highlighted the restricted use of intertidal zones by Kutanda fishers (Figure 2), explicitly identified as largely for women. Table 5.4 further highlights the gender divide in habitat use, with a clear distinction between shallower water habitats and sandflats used by women with Kutanda, and increasing male Chicocota use with increasing depth and complexity of habitat. This is reflected in vessel use, with Kutanda use almost exclusively on foot, though areas that are potentially accessible to Kutanda fishers on foot such as shallow reefs and seagrasses are still largely dominated by male fishers. It is not possible from these data to be certain whether this habitat use is entirely by choice, for example as a female adaptive proximity strategy allowing both productive and reproductive work (de la Torre-Castro *et al.*, 2017) or preference for resources specific to sand flats, or whether forced by social-norm driven gendered division of labour. Either way, in the case of Cabo Delgado our data support the conclusion that whilst men using Chicocota may compete geographically for fishing grounds and fish with other male gears, female Kutanda use competes neither in a spatial sense, nor in a cultural sense by 'threatening' androcentric activities and livelihoods or 'reinforced masculinity' (de la Torre-Castro *et al.*, 2017). In terms of gender equality, MNF may serve to allow women initial access to a fishery and alternative resources in both a non-competitive and socially acceptable manner; a small but significant step towards social equity.

Assumption E: MNF largely targets juveniles

The generally small size of captured individuals in MNs has led to a prevalent assumption of high juvenile capture rates, though empirical evidence is lacking. In Chapter 4, however, a number of small-

bodied species (rather than juveniles) were identified as targets suggesting that the assumption may not always be valid. For Kutanda, total length data (which was unfortunately only collected for this gear) supports a general tendency for capture of small fish (though generalisations cannot be drawn on overall MNF catch in light of the distinctions between deployment methods). The majority of individuals caught were under 10cm (Figure 5.20). The average length of individual recorded, of 48 species, was 7.15cm (S.E. +/- 0.007, n=1130), with the smallest 1.3cm (*G. oyena*) and the largest 43cm (*Hyporhampus affinis*) (Figure 5.20). Larger individuals (>15cm) were rare and dominated by *H. affinis* and *Strongylura incisa.*

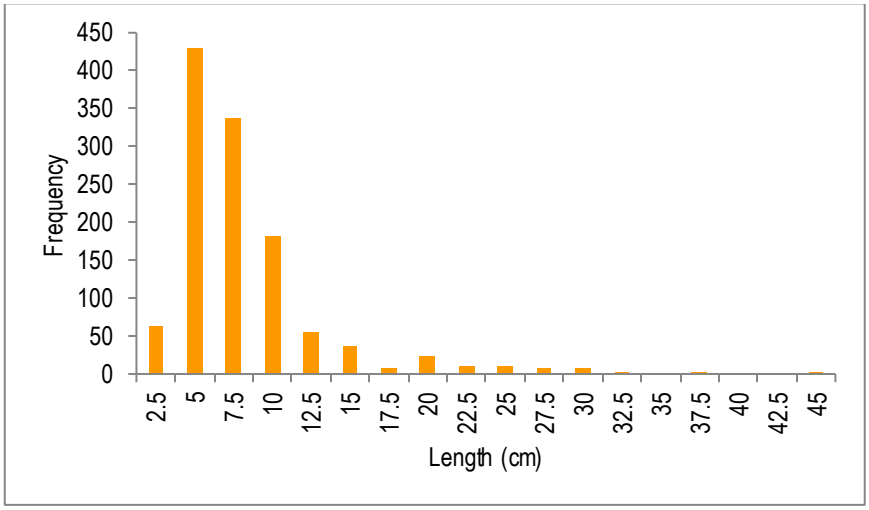


Figure 5.20 - Size-frequency spectrum of individuals caught with Kutanda

Assessing the proportion of each species which were larger than the length at first maturity (Lm) reveals that the assumption that kutanda is dominated by juveniles largely holds, with just five species or groups having mature representatives (Figure 5.21): 0.9% of *G. Oyena* were over Lm (n = 458), 20% of Clupidae (n = 94), 57% of *H. affinis* (n = 21), 25% of *Petroscirtes mitratus* (n = 16), and 67% of *Amblygobius phalaena* (n = 3). Significant adult capture was therefore limited to *H. affinis* and *A. phalaena* (which had a very small sample size*)* with the former also being highlighted in FGDs as important to Kutanda fishers due to its size and consequent value. *H. affinis* not only tends to school in shallow waters, but also has an extended needle-like rostrum which can get caught even in small mesh sizes, potentially explaining its inability to escape. Indeed I observed this occurring during the few fisher follows I was able to conduct. The remainder of the species were represented only by individuals below Lm.

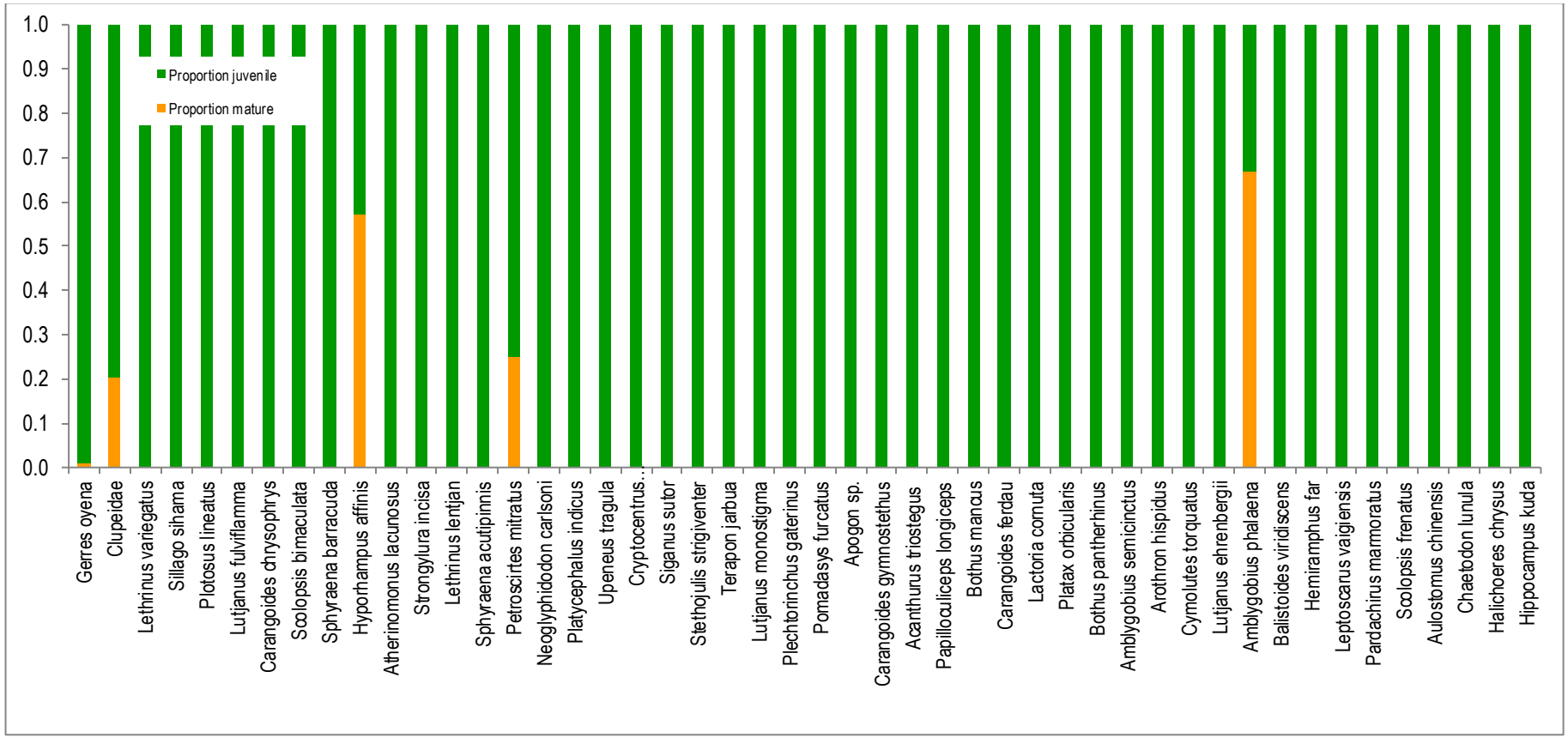


Figure 5.21 - Proportion of Kutanda catch species that are above and below length at first maturity values. Species ordered by relative abundance of those assessed.

Of the predominant species caught, *G. oyena*, just four mature individuals were recorded (0.009%). As this species makes up 88% of the Kutanda catch by weight and 93% by abundance we can surmise that the vast majority of Kutanda catch is of juveniles of just a single species. Similarly, the limited number of other species making up any significant portion of Kutanda catch (supported by the wider landings data) were recorded as entirely juvenile: *Lethrinus variegatus*, *Sillago sihama* and *Plotosus lineatus*. Whilst length at first maturity values can be inaccurate, showing some spatial and population variability as well as being impacted by selective pressures of fishing itself (size truncation), with an average length of 6.2cm (S.E. +/- 0.15) it is clear that the majority of *G. oyena* are well below Lm.

What these juvenile capture rates may say about the sustainability of MNF is difficult to infer with confidence in the absence of full stock assessment, as per the discussion surrounding recruitment overfishing. Indeed, the results of this section provide additional insight as to the potential for recruitment overfishing, which I have previously explored, by confirming suspected juvenile capture rates which are considered detrimental under traditional size-selective management paradigms. Though, as I have explored in more detail in Chapter 2, this may actually be of benefit to fishers under balanced harvest theory. However, it is clear that Kutanda is harvesting individuals not just before they have had the opportunity to breed, but also before they have reached their growth potential in terms of amount of food or revenue that they have the potential to provide. In a socio-economic sense, realistically this is only an issue in the case of species of importance to the wider fishery, which we have shown largely not to be the case for Kutanda.

5.4. Beyond assumptions in Cabo Delgado and more broadly

In this in-depth, within-fishery gear comparison study I necessarily employed an effort measure of per fisher per hour to account for the newly assessed gears of Chicocota and Kutanda where a per day or per trip measure would skew the comparison with offshore gears, which have considerably higher soak times in a trip. However, it is useful to be able to contextualise this within the fisheries of the wider region when considering overall pressure, though these comparisons in highly heterogeneous fisheries are obviously of a coarse nature.

In their concurrent assessment of Cabo Delgado fisheries Samoilys *et al.*, 2018 (In press) employ a per fisher per day measure to OSOL catch data for 2015, giving an average CPUE of 7.9 kg fisher^{-1} trip^{-1} across all gears and recognising this as higher than those of other WIO countries. They find that the small-scale fisheries of Cabo Delgado are equivalent in average CPUE to Kenyan fisheries 30 years ago (Samoilys *et al.*, 2017) suggesting a much slower rate of decline or a more recent intensification of fishing pressure. A catch reconstruction exercise for Mozambique, inclusive of small scale fisheries, conducted by Jacquet *et al.*, (2010) suggests a decline in national catches between 1986-2005 of ~32%

and attributes this to increased pressure from numbers of small-scale fishers. Samoilys et al. 2018 (in review) criticise this somewhat due to a lack of data from Cabo Delgado and a subsequent overestimation of fishing effort in the province, however other studies do support the se declines even in Cabo Delgado (Gell, 1999). Of course we cannot disaggregate an impact of MNF from these studies, and whilst Cabo Delgado fisheries may present as having relatively healthy catches compared to nearby fisheries such as Kenya and Tanzania, the perceived declines in recent years have been attributed to increasing fishing pressure; some of which is likely down to use of MNs or at least Chicocota and which is also likely to worsen if the fishery is comparatively more productive than those from which fishers may be increasingly displaced, providing a "pull" for in-coming fishers.

The data presented here are subject to a number of limitations which have been discussed in the introduction. The methods used were in order to obtain the best data possible in the circumstances, but were not ideal. However, it is clear that in the case of the OSOL sites of Cabo Delgado many of the assumptions which underpin the current policy of prohibition towards MNF are potentially dramatically incorrect. It would be very misleading to assign blame for all of the woes of the fishery to MNF. However, consideration needs to be given to the differing impacts of the two MNF methods. Were the harvest rates recorded here for Chicocota nets occurring for those species deemed valuable to other fishers, there may be an issue of growth overfishing.

A recent analysis of potential rent losses in the Clupidae fishery of the Democratic Republic of Congo's section of Lake Tanganyika estimated that the use of MNs in order to harvest larval individuals of the species *Limnothrissa miodon* has cost legal fishers $2.1 million across the survey area (just DRC). However a number of gaps exist in this study: a) authors note the use of illegal gears to be in response to already declining clupeid catches therefore disaggregation of cause and effect in MNF impacts is difficult; b) the gear use involving MNs, which is described as very similar to Kutanda, is poorly defined and the authors do not distinguish between cod ends of beach seines and standalone gears; c) the study assumes a direct relationship between wet weight of harvested larvae and potential wet weight of harvested adults, not accounting for natural mortality rates and other factors of population dynamics and; d) the opportunity cost is apparently borne solely by male fishers with little discussion as to the beneficial socio-economic nature of the women's MNF catch in comparison. Indeed, an effect of recruitment overfishing is also alluded to in the concluding discussion. Despite the flaws of this study, it does serve to reinforce some of the concerns surrounding MNF and growth overfishing even on a single species, and whilst an empirical investigation of Chicocota impacts was logistically prohibited here, qualitative assertions of high juvenile capture rates highlights a need for urgent investigation, alongside a stock assessment for *G. oyena*.

The importance of distinguishing differences between Kutanda and Chicocota should not be understated in terms of the risk they pose to the sustainability of the fishery. Chicocota appears to not only be more destructive in terms of direct physical benthic damage, but also poses a risk to a greater number of species and a higher likelihood of exhibiting or leading to recruitment overfishing than Kutanda. Additionally, due to the socio-economic context of the case study it could be argued that Chicocota poses a greater risk of expansion, both through prevalence of the activity and further modification of deployment methods. However, these differences are highly context-specific. Whilst in chapter 4 I have demonstrated that engagement by women is high elsewhere in the world, we cannot know that these gender disparities are universal.

For Cabo Delgado there is a need to disaggregate by method and gender going forwards, with distinct lessons to be learned for investigating MNF in other regions. A historical lack of data, admittedly compounded by the logistical issues which I also faced in this study, but also as a result a lack of political will to understand MNF better, has led to ignorance of the real impacts of the activity and harmful scapegoating of the most vulnerable groups and migrants. Rosendo et al. (2011) have suggested that the migrant fishers of Cabo Delgado, coming largely from Tanzania and Southern provinces of Nampula, have been displaced largely by restrictions on gear use (including MNF) and declining catches in their home regions. Animosity and conflict surrounding migrant fishers, sometimes local but more frequently from further afield, is widespread in East Africa (Crona & Rosendo, 2011) and indeed Northern Mozambique (Rosendo *et al.*, 2011). In many cases these fishers have been displaced from their traditional fishing grounds by issues of violent conflict, declining resources or persecution. The tendency for migrants to shoulder the blame for subsequent declining resources in the communities where they end up is common, but not always justified (Crona & Rosendo, 2011; Crona *et al.*, 2010b).

As existing stakeholders in the fishery, the enhanced access to resources for women provided by MNF is arguably a step towards social equity in an otherwise skewed system, where androcentric management can devalue both women's roles and the contributions of intertidal resources (de la Torre-Castro *et al.*, 2017). Whilst this may still ultimately constitute increased pressure on the fishery as a whole (which I discuss further later in light of other assumptions), an argument could be made that under co-management goals of representativeness and inclusion this evolution of women's roles in the fishery is deserving of some status for MNF in management, rather than blanket exclusion. This potential for social equity extends to children too. Cabo Delgado has the highest rates of childhood stunting and malnutrition in Mozambique (Lopus, 2015) and women with access to fisheries resources have been shown in other fisheries to provide better childhood nutrition than households exclusively dependent on male provisioning (Harper *et al.*, 2013).

Questions arising and yet to be answered

One strong lesson was that there is first and foremost a need to improve empirical understanding of the status of the Cabo Delgado fishery, including MNF. This requires tackling both the logistical issues with effective MNF data collection and strengthening the political will to do so. The advancement of co-management in Cabo Delgado, which remains poorly implemented in most villages, alongside trust-building and some immunity for those MN fishers who co-operate with monitoring, would go a long way towards solving many of the access issues for monitoring caused by enforcement policies. MNF can be a relatively quick and spontaneous activity, dependent on daily food needs or word of good catches, so fishers may be additionally unwilling to stop for long monitoring efforts due to hunger or fatigue. Issues of identification of small and damaged fish, and local capacity of IIP staff also need to be addressed. One potential solution is through the use of genetic methods, which may traditionally also be impeded by time-poor fishers, logistics of storing/transporting samples from very remote locations and perceived harm to fishers' catch. However, environmental DNA (eDNA) and genomics technology may offer some promising advances (Barnes & Turner, 2016; Goldberg *et al.*, 2016). By being able to detect species from genetic material in water samples rather than invasive collection of tissues, development of a monitoring system which negates the need for catch sorting or sampling and identification in-situ would be hugely beneficial.

The landings data presented here are critically limited by the rapid assessment methodology and really provide just a snapshot of the fishery for initial assessment. Monitoring efforts should aim for a longer-term time series for the fishery, perhaps using participatory methods involving local fishers, and using these data as a baseline against which to compare changes. Whilst census data is useful in painting a picture of how many fishers may engage in MNF, we were not able to extrapolate this to a conclusion on overall effort and therefore inferences about fishing pressure. Importantly, these data are unable to support empirical conclusions on the seasonality of MNF, which was described in FGDs as of some importance. FGDs alluded to several potential drivers of this seasonality; firstly alternative time commitments to agriculture in planting and harvesting seasons which are seen as increasingly unpredictable with impacts on yields. It is possible that more people will turn to or increase their fishing efforts as agricultural yields become less reliable; longer term monitoring would be able to capture these changes. Secondly, weather and particularly winds were seen to impact the decision to fish on a daily basis, but there were some inconsistencies in what is favoured; so again further data collection would aid understanding.

The seasonal availability of certain favoured species may be of critical importance to understanding the impacts of MNF as both Kutanda and Chicocota target habitats that are critical nursery grounds for

many pelagic and reef species. OSOL project staff have recently highlighted qualitative evidence of the targeting of spawning aggregations by some fishers (not necessarily MN fishers). The fine mesh size of MNs is of potentially greater concern if fishers are targeting large aggregations of fish in both nursery and spawning grounds. The use of participatory monitoring and employing accessible technology solutions such as Open Data Kit for data collection (Blue Ventures, 2018), across all gears, would help to circumvent some of the logistical issues of working year-round in these remote villages, such as access during the rainy season.

It is incredibly important not to extrapolate the results presented here to other situations. Possibly the most pertinent question arising from these results is how they might compare with other case studies in other locations. Fisheries are highly variable, and there is already evidence from elsewhere that MN fishers are not always predominantly women (Bush *et al.*, 2016). The evidence in Chapter 4 shows the variability in scale of deployment methods. There are likely to be large differences between marine systems such as this one and freshwater systems such as the African Great Lakes, where there has been alarm over the scale of fishing and perceived declines (McLean *et al.*, 2014). Detailed investigation of MNF in other regions is a crucial next step.

Conclusions

By providing the first in-depth characterisation of its kind of an MN fishery, and providing evidence which strongly questions prior assumptions, we have provided the incentive for a concerted, rigorous and widespread investigation of MNF in the context of wider fisheries management. Whilst it has not gone unrecognised that there are food security and livelihoods benefits to MNF (McLean *et al.*, 2014; Gettleman, 2015; Larsen *et al.*, 2018), these have been considered short term, marginal and unsustainable based on the assumptions questioned here. Some of the evidence here begins to counter this and aligns more with ideas of BH; suggesting that not only does Kutanda have limited overlap in terms of resource exploitation with other gears, but that as a standalone activity it may show promise of sustainability by harvesting a resilient species at a particularly productive life stage (Garcia *et al.*, 2012). Kutanda MNF showed an average CPUE that was not hugely different from that of other gears, which may be due to overall declining catches and a 'fishing down the food web' effect, or which may mean that MNF is a significant and relevant contributor to food security both locally and further afield. With Kutanda acting as an access point to the fishery for women and other marginalised groups, it may go some way to redressing some of the inequalities present in fisheries exploitation and benefit sharing, particularly in small-scale fisheries (Obregón *et al.*, 2018; Bennett, 2018) and those in particularly conservative regions such as Cabo Delgado (Wosu, 2018). Combined with the growing body of evidence of huge nutritional benefits from the types of small-bodied catches observed in these data

(Thilsted *et al.*, 2014; Bogard *et al.*, 2015), there is a building argument for recognising the broader positive impacts from MNF, potentially even on malaria survivorship through improved micronutrient provision (Caulfield, Richard & Black, 2004). Concerns over MNF follow a Malthusian narrative; the consequent assumptions can lead to ignorance about the health, wellbeing and social equity benefits that MNF may provide. A more holistic view of MNF contributions to overall wellbeing in communities is necessary and in the next chapter I will begin to address some of these questions using the same Cabo Delgado case study.

6. Got bigger fish to fry?

The role of mosquito net fishing in livelihoods and food security in Northern Mozambique.

6.1. Introduction

Mosquito net fishing continues to be discussed within scientific and governance-related circles almost exclusively in terms of its potential negative impacts on sustainable food security and biodiversity (e.g. Gettleman, 2015; McLean *et al.*, 2014; Mwareya, 2016), portraying it as a desperate, last resort activity driven by extreme poverty and reduced access to alternative resources. The concept of fishing as an 'occupation of last resort' has been a pervasive narrative in the fisheries and development literature, but is increasingly challenged (Béné, Hersoug & Allison, 2010; Béné, 2003; Béné *et al.*, 2009; Cinner, Daw & McClanahan, 2009). There is some anecdotal evidence that MNF may be such an activity of last resort (Bush *et al.*, 2016), but starkly missing from the MNF literature is any detailed analysis of either the underlying drivers of MNF or its socio-economic impacts (positive and negative). To understand the role of MNF as a potential safety net of last resort or otherwise, we need to better understand the drivers and impacts of this activity at both individual and community levels.

At the individual level MNF has been broadly characterised as an activity primarily dominated by women, and with a mix of both experienced fishers and inexperienced new entrants (Bush et al 2016; Chapter 4; Chapter 5). The perceived engagement of women and those marginalised from other occupations supports the idea that MNF is a fall-back in times of hardship or for those who may lack access to alternatives for cultural reasons. Perceptions of conservation and development professionals around drivers for engagement in MNF in Chapter 4 did show a focus on poverty, with suggestions that declines in alternative resources may be a driver. However, additional drivers included ease of access to gear, convenience, and comparatively good catch rates. This range of drivers complicates the picture and suggests there are significant attractions to the activity beyond the last resort narrative. In Chapter 5 I have shown the different but important engagement of men in MNF, with evidence that male fishers have converted to the gear or added it on to existing activity portfolios, rather than it being dominated by new entrants. Both of these points challenge current narratives around MNF but as yet there have been no empirical studies that directly assess the characteristics of households engaged in MNF and how those households compare to those that are not engaged in MNF. Nor has there been analysis of the drivers for MNF at the individual level from within MNF communities.

The negative MNF narrative predicts overall fisheries declines for communities with MNF, leading to food security impacts regardless of whether the household engages in MNF. Positive benefits to communities from the food MNF provides are viewed in this narrative as short term at best. There are also potentially lucrative external markets for MNF catch, both for human consumption elsewhere and as animal feed, offering commercialisation opportunities which may undermine the direct nutritional contribution of MNF to communities (Chapter 3). However, in Chapter 5 I questioned the reflexive labelling of MNF as highly unsustainable. MNF may play a role in promoting greater equity in fisheries as an entry point for the marginalised, and make long term livelihood and food security contributions directly for fishers and for their wider communities (Chapter 2). Given that I have additionally discussed the huge potential failings of a purely enforcement-focused approach to MNF management (Chapter 2), widening the narrative from one of unsustainable and illegal activity to provide a more nuanced understanding of the role and importance of MNF in livelihoods at both an individual and community level will be crucial to effective management.

A particularly useful framework for guiding analyses of the role of MNF is that outlined by Dorward *et al.*, (2009). This paper recognises the role of diverse livelihoods, building on research which posits that diversification of livelihoods for the poor is not necessarily absolute (trading one occupation off for another completely), particularly in fishing communities, but can be a consistently adaptive engagement in various livelihoods which vary temporally in response to socio-economic/environmental change, relative outcomes or resource availability (Allison & Ellis, 2001). The balancing of production patterns with consumption needs can be viewed as applying to one or more of three strategies: 'hanging in' on the current livelihood levels; 'stepping up' by utilising current activities to invest in assets and improve the productivity of these activities; and 'stepping out' by accumulating assets with which to enable entry to an alternative, more productive activity. Determining the role of MNF according to this typology will be key to developing appropriate management: does MNF simply fill the stomachs of people with no other access to animal protein; serve as a means to engage with the wider fishery or enhance concurrent agricultural productivity (playing more of a 'bank in the water' role than previously thought); or convey a significant economic advantage helping families to invest in enhanced strategies and improving wellbeing?

In this chapter I will again use the case study location of Cabo Delgado, Mozambique to provide the first empirical investigation of the role of MNF in local livelihoods and wellbeing that draws information directly from the households and communities engaged in MNF. Cabo Delgado has a complex and rapidly changing socio-economic situation (Chapter 1). Though poverty in Mozambique is declining, it remains in the top 10 poorest countries in the world (ranked 8th in 2016, United Nations Development Programme, 2017) and Cabo Delgado, as its poorest province, bucks the national trend with increasing

poverty rates, up 5% between 2009-2015. The area has largely been extremely isolated from formal markets, and despite rapid growth in the cash economy in recent years, driven by a boom in oil and gas and other extractive industries, there has been little positive impacts on local people due to elite capture and barriers to engagement in industry by people with low education levels (Wosu, 2018). As a consequence, livelihoods still largely focus around subsistence fishing and agriculture, with fishing playing an increasingly important role due to climate-related declines in agricultural productivity (Riddell & Rosendo, 2015; Rosendo *et al.*, 2011). These characteristics of chronic poverty are perceived to have led to the rapid increase in MNF highlighted in Chapter 4 in the region. This study site is therefore a particularly relevant case study of the role of MNF in livelihood responses, given the increasingly difficult situation faced by its communities.

This chapter mainly focuses on an in-depth quantitative analysis at the household level of two of the Our Sea Our Life (OSOL) sites, Malinde and Quirinde (Chapter 1). The household level is our unit of interest as it is the scale at which group decisions are made (Allison & Horemans, 2006) and is the operational unit of both adaptability (livelihood diversification potential) and vulnerability (collective impact of shocks). I complement this household-level data with qualitative community-level analyses from the broader region (including the remaining 4 OSOL sites) to give greater insights.

At the household level this chapter aimed to explore whether MNF is an occupation of last resort, engaged in by the poorest and most food insecure households of the region (hanging in), or whether it may offer opportunities for expanding fishing activities (stepping up) and improving household wellbeing, or even opportunities for investment in alternatives (stepping out) (Dorward *et al.*, 2009). I compare household wealth and food security between those engaging in MNF and non-MNF (nMNF) households. I also investigate associations between MNF and indicators of household vulnerability, predicting that MNF households will exhibit higher vulnerability associated with: spreading of risk and uncertainty between multiple occupations as an adaptive response to chronic poverty (Zimmerman & Carter, 2003); reduced access to the wider economy (assets and abilities) (Bebbington, 1999; Teh *et al.*, 2008); vulnerable household demographics (gender ratios and number of dependents) (Carney, 1993); and limited social assets (standing in the community) (Ellis & Allison, 2004). I assess whether MNF is prioritised in terms of relative time investment as an immediate returns activity (bank in the water), alongside use of other fishing gears, compared to the discrete returns activity (savings accounts) of agriculture (Béné *et al.*, 2009) and how these two approaches pay off in terms of food and income. I predict that MNF households will be more likely to trade-off food production with disease protection, by using MNs for fishing rather than as bednets (Chapter 2). Other perceived risks and benefits of MNF are also explored qualitatively at the household level.

At the community and broader regional level I explore whether MNF contributes to nMNF household food security, as beneficial access to the resource is not necessarily limited to direct exploitation, and additionally explore this aspect in the wider region by looking at the influence of MNF on fish trade external to the target villages. I also explore community-level perceptions of MNF in terms of drivers and impacts, risks and benefits that have influence beyond the household level.

6.2. Methods

I collected a combination of quantitative data that enabled comparison between MNF and non-MNF households and qualitative data from Focus Group Discussions (FGDs) and key informant (KI) interviews (fish traders) to understand the drivers and potential impacts of MNF at both a household and community level.

Study sites

The Villages of Malinde (District of Mocímboa da Praia) and Quirinde (District of Palma) within Cabo Delgado were selected for this study. Information on number of mosquito net fishers in Mozambique by village is extremely limited. One of the few projects to have undertaken a census of fishing gears in a small number of villages was the OSOL project (Samoilys *et al.*, 2018). Two of the villages assessed by OSOL were selected because of the presence of a high number of mosquito net fishers. These villages were also selected because community fishing councils (CCPs) were still not implementing mosquito net fishing bans and therefore mosquito net fishers were open to talking about their activities. Malinde and Quirinde are also comparable in demography and socio-economics, being the two most populous sites and both being geographically close (<1hr drive) to local centres of commerce. Quirinde is closest to Palma, the main town of Palma district, and Malinde is closest to Mocímboa da Praia, the main town of Mocímboa district (Figure 1.2).

Household survey

A structured household survey was conducted in both villages of Malinde and Quirinde between 5th October and 27th November 2016. OSOL census data recorded household activities by individual thus acting as a sampling frame and enabling a stratified random sample of roughly equal numbers of MNF and nMNF households to be identified in advance. Households could be identified from the census data by numbers written on door frame structures. Migrant households were opportunistically interviewed as these were excluded from census data; here instead every second dwelling was visited.

A total of 246 households were interviewed across the sites with a roughly 50:50 split between MNF and nMNF households at each site (Table 6.1). Households were approached as per the randomly sampled list and a structured introduction to the project was used (Appendix D). As the questions were

aimed at reporting at the household level respondents were only interviewed if a senior member of the household was present, otherwise a re-visit was attempted at another time of day (preferably pre-decided). The purpose of the household survey was to collect data on socio-economic variables of relevance to potential MNF drivers and impacts at the household and community level. First, socio-economic indicators of potential household vulnerability (education and literacy, number of dependents, assets and savings, female role, residency, food security, occupational diversity and use of bednets) were collected for comparison between MNF and nMNF households alongside self-assessments of income and food contributions from household activities as compared with time commitments for both sets of households. These indicators were decided upon following lengthy discussion with local staff and consideration of the literature to decide upon their relevance in the local context and to ensure it would be information people were likely to be comfortable in divulging. Second, qualitative data on perceptions of risks and benefits of MNF were collected using a visual framework (Appendix D.11) in order to shed light on both household and community level effects of MNF, as well as perceived environmental impacts. Data were collected using local translators, with Mozambican research assistants acting as intermediary translators; recording data in Portuguese as English speakers are rare in the region. Questionnaires were subsequently translated upon return to the UK by a native Portuguese speaker. There was no evidence of local translators affecting willingness to admit engagement in MNF (as an illegal activity) as just two households identified as MNF households in the census data later stated that they did not engage and reasonable justification was given (person who engaged had left the household).

Table 6.1 - Numbers of household interviews conducted at each site and for each type of household.

Village	MNF hh	nMNF hh	Total	Survey dates
Malinde	69	59	128	5/10/16 – 23/10/16
Quirinde	58	60	118	17/11/16 – 27/11/16
Total	127	119		

Data analyses

Material style of life and economic mobility scores

Material style of life scores were calculated and allotted to each household using principal component analysis (PCA) across a set of variables related to material wealth (Table 6.2). Locally suitable variables were developed based on prior research conducted by the OSOL project alongside consultation with local staff and refined based on the household survey pilot data.

Table 6.2 - Principal components analysis (PCA) of household material style of life wealth indicators. The five Principle Components (PCs) accounting for the majority of the variation are shown. The cumulative variance for each PC is shown, with a drop off following PC5 (scree plot is displayed in Figure D.), along with the loading co-efficients of each variable towards that PC (co-efficients over +/- 0.35 are in bold).

Variable	Type	Description	PC1	PC2	PC3	PC4	PC5
Floor type	Score (1-2)	1 = mud, 2 = concrete	**0.40**	-0.13	0.11	-0.28	**0.38**
Wall type	Score (1-6)	1 = straw, 2 = daub & wattle, 3 = improved daub & wattle, wood or metal, 4 = concrete	**0.43**	-0.30	0.00	-0.14	0.27
Roof type	Score (1-2)	1 = straw, 2 = metal	**0.41**	-0.28	0.01	0.28	0.10
Bicycle	Count (0-2)	Functional	0.15	**0.43**	**0.57**	0.06	-0.25
Motorbike	Count (0-1)	Functional	0.26	0.24	**-0.50**	-0.11	-0.20
Canoe	Count (0-2)	Dugout (man-powered)	0.12	**0.49**	**-0.38**	-0.19	0.29
Dhow	Count (0-2)	Sailboat (wind-powered)	0.17	-0.18	**-0.41**	**0.51**	**-0.41**
Goats	Count (0-28)	Live	0.14	-0.09	0.09	**-0.49**	**-0.58**
Chickens	Count (0-25)	Live	0.29	0.13	0.29	**0.46**	0.05
Coconut trees	Count (0-100)	Live	0.30	-0.25	0.06	-0.24	-0.28
Electricals	Count (0-7)	Functional solar panels, radios, mobile phones	**0.41**	**0.46**	-0.01	0.05	-0.08
Cumulative variance explained			**22.7%**	**35%**	**45.4%**	**55.3%**	**64.7%**

Economic mobility scores were calculated and allotted to each household using PCA across a set of variables related to a households ability to engage in the wider local economy (Table 6.3). Variables were selected based on consultation with local staff about what aspects of a household enable them to do well, gain economic opportunities and engage with a larger social/geographic arena. Variables were then refined based on the household survey pilot data.

Table 6.3 - PCA of economic mobility indicators. All three PCs are shown along with loading co-efficients of variables (co-efficients over +/- 0.35 are in bold). Much of the variance is explained by PC1 (scree plot is displayed in Figure D.).

Variable	Type	Description	PC1	PC2	PC3
Highest level of education	Integer (0-12)	Highest level of education attained by any member of household	**0.61**	**-0.37**	**-0.70**
Proportion literate	Proportion (0-1)	Proportion of adults in household who are literate	**0.61**	**-0.35**	**0.71**
No. of languages	Integer (1-7)	Cumulative languages spoken by household members	**0.51**	**0.86**	0.01
Cumulative variance explained			**70%**	**90.6%**	**100%**

Household Food Insecurity Access Scale (HFIAS)

HFIAS scores were collected alongside the main household questionnaire and calculated as a household average across 5 indicators of experienced household food insecurity over the previous 12 months, each scored between 0 (never) and 3 (often). Indicators were adapted for local relevance from Coates, Swindale & Bilinsky, (2007) in consultation with local staff and researchers followed by a pilot where the indicators were refined.

Statistical analyses

Probability of households using MNF were first analysed as a function of household characteristics, food security and wealth indicators (fixed effects) using Binomial Generalised Linear Mixed Models to account for structure in the data from both site (village) and enumerator (random effects). Model selection was based on an information-theoretic approach using comparisons of Akaike Information Criterion (AIC) (Bolker *et al.*, 2009). However, following the determination that the random effects had no significant impact on model fit, with no difference between marginal and conditional R^2 values (0.4104833 and 0.4104834 respectively) and no reduction in AIC value when included, fixed effects were ultimately analysed using Binomial (Bernoulli) Generalised Linear Models.

Mann-Whitney U tests were used for comparison of proportional livelihoods data and health (malaria) indicators.

All data analyses were performed using R 3.5.0 (R Core Team, 2014).

Currency exchange rates for conversion of Mozambican new meticals (MZN) to U.S. dollars were sourced from https://www.oanda.com/currency/converter/ for the start of the survey period (5/10/16).

Focus Group Discussions

Data on socio-economic aspects of MNF were collected in the same FGDs as aspects of the fishery's characteristics. Please see Chapter 5, Section 2.1 and Appendix C.2 for more information on data collection, storage and ethical management.

FGDs were conducted in the most appropriate language for the location, dependent on staff availability (usually Kimwani but also Kiswahili, Kimacua, Kimakwe). Notes were taken by the author from simultaneous translation into English, followed by a formal write-up upon next access to a source of electricity. Once transcribed, FGD responses were coded by the author with a focus on their relevance to the study objectives and/or novelty of information. Responses were categorised by gender and location. Subsequently the transcriptions were searched for evidence corroborating or refuting inferences arising from quantitative data analyses. Relevant information was included in the results if corroborated by at least one other respondent from an alternative FGD. If information from a single respondent or single FGD is presented this is stated as such. Quotes are used to illustrate the themes included in results and were selected by the author based on clarity of language and relevance to the point being made.

Trader interviews

Two male traders of catch from MNF (medada) were interviewed in November 2016 opportunistically, as they are infrequent visitors to the sites for trade. One trader (in Malinde) was a generalist trader who happened to trade in medada whilst the other (in Quirinde) was a specialist trader in medada from MNF. Interviews lasted 30 minutes and 1hr 10 mins and utilised both direct and indirect translation (two-way) dependent on the staff available. Whilst further interviews were attempted for the full duration of the household survey, no traders were available during this data collection period.

6.3. Results

Is probability of engagement in MNF a function of socio-economic correlates of vulnerability?

In order to understand socio-economic correlates of engagement in MNF a comparison of household characteristics related to vulnerability was undertaken using a number of potentially influential variables.

Demographic variables

Four of the 11 potential variables related to MNF engagement (Table 6.4); occupational multiplicity, proportion of adults considering themselves primarily a fisher, and the proportion of the household that are female had positive effects on engagement in MNF, whereas the residency status of the household had a negative effect on engagement. Importance values were 1 for all four variables, and effect sizes did not show large variability. Means and standard errors, along with graphical representations, for these variables are provided in Appendix D. Occupational multiplicity, defined as the number of different activities engaged in across the household, was higher in MNF households by 0.21 occupations (Figure D.6C). MNF households also tend to have a higher proportion of adults who consider themselves fishers as a primary occupation, but only marginally (Figure D.6B). MNF households tended to be those with a higher proportion of adult women compared to men (0.118 people, Figure D.6A). However whether or not these households were female headed was not a significant predictor of engagement. MNF households were also marginally but significantly less likely to be a migrant (itinerant) household (10.2% fewer households, Figure D.6D).

Table 6.4 - Parameter estimates for the model averaged household characterisation variables from a binomial (Bernoulli) generalised linear model, with the binary response variable of whether or not a household engaged in MNF. Economic mobility values are proxied by PCA scores (Table 6.3). All candidate variables from the original global model are listed.

Continuous/discrete variables	**Estimate (SE)**	**z value**	**Importance value**	**P-value**	**Significance**
Intercept	0.118 (0.14)	0.814	-	0.415	ns
Household size	Excluded from final model				
Occupational multiplicity	1.144 (0.33)	3.46	1	<0.001	***
Proportion hh primarily fisher	0.94 (0.33)	2.803	1	0.005	**
Proportion of hh <16yrs	0.082 (0.21)	0.39	0.23	0.697	ns
Proportion of hh female	1.84 (0.4)	4.607	1	<0.001	***
Economic mobility (PCA1)	Excluded from final model				
Categorical variables (0/1)					
Started fishing last 5 yrs (y=1)	-0.033 (0.18)	0.186	0.14	0.852	ns
Leadership position (y =1)	0.8 (0.6)	1.345	0.84	0.179	ns
Household head female (y=1)	-0.042 (0.22)	0.195	0.14	0.845	ns
Household are itinerant (y=1)	-1.45 (0.6)	2.38	1	0.017	*

Wealth/asset indicators

Analysis of wealth indicators of material style of life, income change over the previous 5 years and savings group membership with a binomial GLM favoured the null model when comparing AIC values, indicating no relationship between wealth and probability of MNF engagement (Table D7) . Averaged over all households a decline in income of 16.8% (SE +/- 2.9) in the previous five years was reported.

Food security indicators

Food security indicators that were assessed in relation to household MNF engagement included the general indicators of Household Food Insecurity Access Scale (HFIAS) scores and access to saved dry food stuffs, as well as an MNF specific indicator: number of days per week medada is consumed by household in both the rainy (wet) and dry seasons. Days medada was consumed showed a significant effect on MNF engagement only for the rainy season (Table 6.5) when MNF households were consuming this catch an average of 1.1 extra days per week compared to nMNF (Figure D.6; Table 6.5), though nMNF households were still consuming medada an average of 2.8 days per week. In the dry season this rate of consumption decreased for both household types, but did not significantly vary between them. Saved dry food stuffs were common amongst households, with an overall proportion of 46% of households having food stores at the time of the survey, though this did not differ significantly between the household types.

Table 6.5 - Parameter estimates for the model averaged food security from a indicators binomial (bernoulli) generalised linear model, with the binary response variable of whether or not a household engaged in MNF. All candidate variables from the original global model are included.

Continuous/discrete variables	**Estimate (SE)**	**z value**	**Imp. value**	**P-value**	**Significance**
Intercept	-0.078 (0.15)	0.537	-	0.591	ns
HFIAS score	Excluded from final model				
Medada consump. (rainy)	-1.086 (0.31)	3.465	1	<0.001	***
Medada consump. (dry)	-1.53 (0.32)	0.471	0.36	0.638	ns
Categorical variable (0/1)					
Saved food (y=1)	-0.368 (0.32)	1.255	0.18	0.209	ns

Health indicators (malarial risk)

No significant difference in net availability (number of nets per person) was reported between MNF and nMNF households. However, a significant difference in self-reported coverage (proportion of hh sleeping under a net 'usually') was recorded, with MNF households having an average of 73% (SE +/- 3.3%) of the inhabitants sleeping under a net compared with 61% (SE +/- 3.9%) in non-MNF households (Figure 6.1).

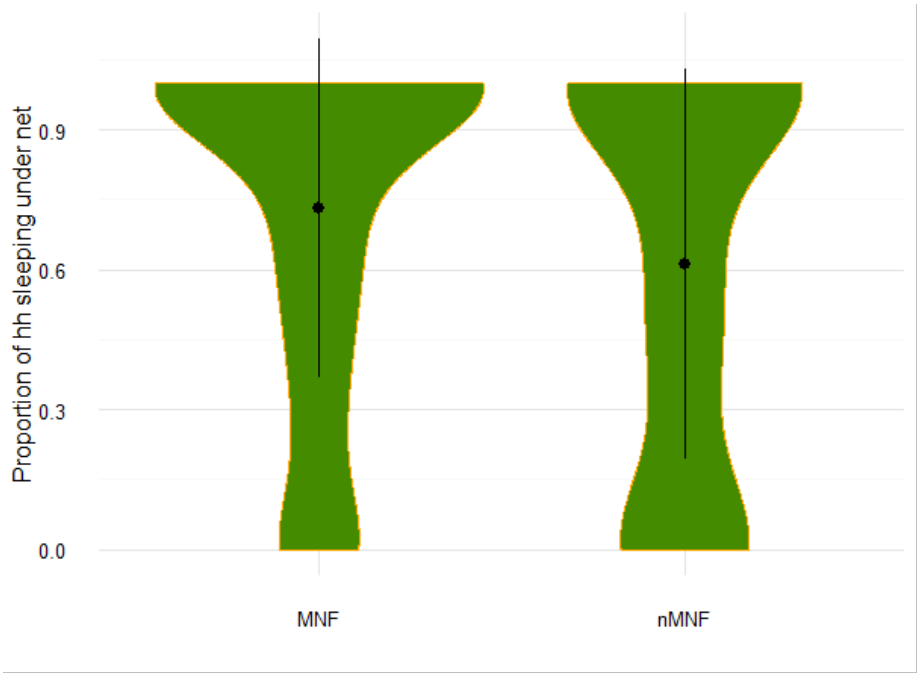


Figure 6.1 - Violin plot showing distribution of proportion of households 'usually' sleeping under a mosquito net in those households engaging and those households not engaging in MNF. Black dots and lines are mean values with standard deviations. Mann-Whitney U test, W = 7529.5, p-value = 0.036.

Perceived drivers of MNF at the household level

Focus group discussions with women at the OSOL sites largely agreed upon a preference for farming over fishing as a primary occupation, saying farming is "more important", though there was frequent recognition that access to "curry" (which requires fish for flavour) was an important contribution from MNF. MNF is openly reported by many as a last resort, catch-22, livelihood with a number of drivers, many of which are related to agricultural decline. Specifically, this related to impacts on meeting subsistence needs from agriculture of lessened and unpredictable rainy seasons, crop raiding by monkeys and elephants and a lack of access to seeds (which largely limits crops to cassava and rice). Reduced catch in the wider fishery was given less emphasis than those drivers connected to agriculture, but was identified by all groups and linked to food security. Women reported a lack of access to "business" income meaning MNF was their only option.

Women were often unwilling to discuss Chicocota and specific drivers of this activity, due to associated taboos and social risks. In male FGDs, the main perceived driver of the more profit-driven Chicocota was a recent and rapid decline in fishery resources (last 10-15 years), particularly reef fish, attributed to migrant fishers and the use of beach seines. There was a strong emphasis on a switch from hand lines to Chicocota. More generally, men reported a lack of access to nets in the villages which, were they able to afford them, would enable them to go offshore and get "better catch".

"*The world is changing. The places we can fish are changing – now you can only find [fish] in places like Quirimbas. People from Palma have a reduced resource, the village and province has used all the resources and now people have to go far and use new methods*." Male respondent, FGD Quirinde.

"*People are coming from places that are already overfished and they have destroyed, like Nacala. They are taking the money elsewhere, our businesses aren't even supported"* Male respondent, FGD Quirinde.

Men in the village of Quirinde reported that Chicocota is currently only conducted by outsiders (since 2014, from neighbouring villages or migrant fishers) but that young men from the village were beginning to learn the methods, though they cannot yet use Chicocota without assistance. The targets reported were shrimp and medada with specific medada traders reportedly coming from the nearby town of Mocímboa da praia (also the name of the district) to buy catch. Fishing groups are more formalised than women's, with a net owner inviting a limited number of net operators to split the catch accordingly.

Perceived role of MNF in households

Generally MNF is seen as a subsistence activity, bringing income only when there is surplus catch. It is not clearly distinguished from the long-standing Kutanda fishing method using cloth which, was traditionally used as a reactive subsistence strategy to daily fluctuations in food availability and has been superseded by MNF (though prior to the advent of MN distribution, wealthy fishers could also afford to buy [their wives] fruit netting to fish with):

"*I didn't eat yesterday or today, I have my net, let's go fishing*". Female respondent, FGD Quiwia

The combination of farming and fishing was also seen as important and MNF was reported as important when "*you cannot wait*" and when farming time-lags are limiting food supplies:

"*You can farm a large area but not get much from it and it is getting worse. You don't get enough from doing either activity and neither is reliable.*" Female respondent, FGD Lalane

"*Farming allows just one harvest, for daily needs you need this type of fishing*." Female respondent, FGD Malinde

However, one FGD with women in Malinde reported that the priority is to sell the catch, though they may keep some for themselves. Here MNF was stated as "helping people to do well". Women elsewhere also referred to MNF as "useful" owing to the rapid and sometimes substantial income (up to ~$200 between 3 people being the maximum quoted income from a single trip). Another female FGD reported that income from MNF is important for agricultural investments (tools and seeds). One group in Malinde additionally mentioned MNF facilitating their ability to engage in savings groups – every woman in this FGD (x5) belonged to a Village Saving and Loan Association (VSLA) (Chapter 1). However, numerous groups also stated that income from MNF was most often used to buy staple foods, particularly xima (maize or cassava flour) when they ran out. Many of those who professed to engaging in MNF said they feel they need to continue, but would prefer "better" nets (often citing 'Nhavo' nets, which are ½ - 1" shrimp nets).

Women reported that MNF does not occur in formal fishing groups, but are based on personal relationships and often conducted with neighbours, family or friends, where nets may or may not be shared. One group professed to MNF being "social time" where they could encourage and direct each other to fish.

Discussions often distinguished between Kutanda and Chicocota methods as separate issues, particularly with regards to environmental impacts (Chapter 5). Men reported Chicocota as commercial. Despite this, the majority of men reported that it was an additional occupation to farming and sometimes gleaning (sea cucumber and oysters) and that they sometimes consume the catch. Chicocota was reportedly introduced by fishers from Nampula in the south and Tanzania to the north in the last 5 years (since 2011).

How does MNF fit into household livelihood portfolios?

FGDs showed some variability in the perceived importance of MNF to both incomes and subsistence, with a bearing on the sorts of time investments people made. Whilst many respondents proclaimed MNF to be a quick and reactive activity, which may also be irregular in terms of frequency of engagement, there was also an almost universal consensus that life would be extremely difficult without MNF. The proportion of food contributed by fishing did not depend on whether or not a household was engaged in MNF, but MNF households did report a slightly higher proportion of income from fishing (Table 6.6). This income difference is not reflected in time expenditure for fishing, which shows no difference between the household types. The small income increase appears to be offset by

slightly reduced incomes from farming, however this relationship did not show statistical significance therefore we cannot infer a clear trade-off between different activity categories.

There is evidence of subsistence activities outside of farming and fishing. FGD discussions reported a very small minority of people reliant on subsistence activities in the fringing dry coastal forest, mainly small amounts of bushmeat hunting, including burning of the forest to flush rats for consumption. There was a negative stigma attached to these activities, even compared to MNF, as it was considered to be done by families/individuals who were the very poorest or most disadvantaged.

These results show that, at least within fishing contributions, MNF can be of quite significant importance (Table 6.6). In terms of income, contributions from MNF are roughly equal to that of gleaning (an average of 25.9% and 28.7% respectively), despite households reporting less time commitment to MNF than to gleaning. Though it is worth noting that FGDs highlighted one advantage of MNF to be that gleaning activities could, to some extent, be conducted concurrently. MNF was also perceived to contribute more than a quarter of fishery subsistence contributions to households, with respondents claiming an average of just under a quarter of household time being spent on the activity.

Just 34% of hh (n = 116) report entering the MN fishery in the last 5 years, with the remaining 66% having used MNs for fishing for longer than 5 years (prior to 2011). Fifty two households were able to give a confident year of first engagement in MNF, with the earliest stating the year of independence (1975). Ten of these claimed it was the previous year (2015), which coincided with a mass distribution of nets to the area in 2014-2015.

Table 6.6 - Summary statistics and significance tests using Mann-Whitney U tests for household livelihood portfolios as a self-reported proportion of income made, subsistence needs met and time spent between all activities engaged in by the household. 'All households' is inclusive of MNF and nMNF households and generalises all fishing activities. 'MNF households' is inclusive only of those engaging in MNF and breaks fishing portfolios down by gear use at the household level.

All households

	n (nMNF : MNF)	Mean prop. (SE)		Sig.
		nMNF hh	MNF hh	
Proportion income from fishing	111 : 126	0.396 (0.034)	0.492 (0.026)	* (W=8324.5, p=0.011)
Proportion income from farming	111 : 126	0.440 (0.03)	0.387 (0.025)	ns
Proportion income from other activities	111 : 126	0.155 (0.03)	0.113 (0.023)	ns
Proportion food from fishing	110 : 124	0.342 (0.028)	0.367 (0.016)	ns
Proportion food from farming	110 : 124	0.615 (0.029)	0.626 (0.016)	ns
Proportion food from other activities	106 : 115	0.035 (0.015)	0.007 (0.004)	ns
Proportion time spent fishing	111 : 122	0.363 (0.032)	0.367 (0.024)	ns
Proportion time spent farming	111 : 122	0.529 (0.032)	0.541 (0.025)	ns
Proportion time spent on other activities	111 : 122	0.109 (0.025)	0.084 (0.017)	ns

MNF households

	N	Mean prop. (SE)
Proportion income from gleaning	214	0.287 (0.028)
Proportion Income from MNF	211	0.259 (0.033)
Proportion Income from other gears	209	0.459 (0.033)
Proportion food from gleaning	212	0.325 (0.025)
Proportion food from MNF	209	0.265 (0.032)
Proportion food from other gears	207	0.429 (0.032)
Proportion time spent gleaning	210	0.327 (0.03)
Proportion time spent MN fishing	209	0.241 (0.034)
Proportion time spent on other gears	207	0.445 (0.032)

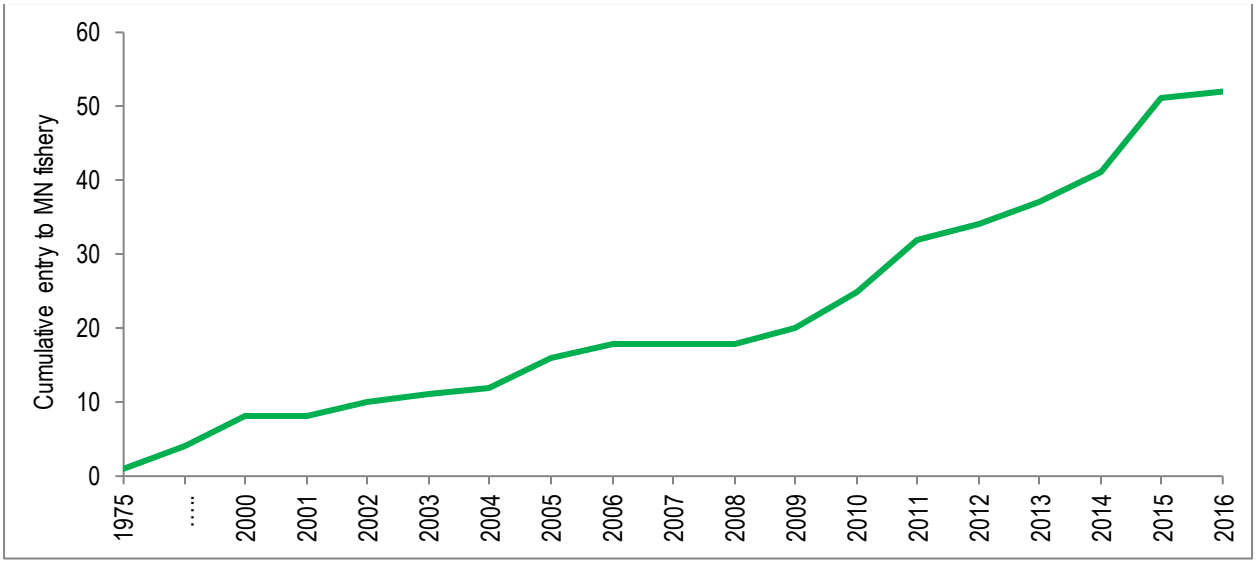


Figure 6.2 - Cumulative respondents stating first year of engagement in MNF (entry to the fishery) from the household survey (n = 54)

Households' predicted responses to scenarios of change in the fishery are presented in Table 6.7. The behavioural response of fishers to the smaller magnitude of change scenario (minus 20% catch size) is roughly equivalent for both MNF fishers and those using legal gears, except that 4% more MNF fishing households reported they would exit the MNF fishery under this scale of decline, than fishing households more generally reported under general fishery declines. This difference increases slightly under a scenario of greater declines (-50% catch size) to 7.2%. However, where willingness to exit roughly doubles with regards to the MNF fishery under a scenario of greater decline, it almost triples for fishers using other gears. A shift of fishing grounds was the most likely response to both scenarios for any gear type, though in reality the magnitude of such a change would vary significantly for MNF fishers, who are constrained to intertidal zones, compared to offshore gear users.

Table 6.7 - Self-predicted behavioural response to scenarios of catch declines for general fishery catch (all households engaged in fishing, all legal gears) and MNF catch (only MNF households, just MNF gears inclusive of Chicocota) as a reaction to both 20% and 50% declines in catch.

	MNF catches - 20%	Other catches - 20%	MNF catches - 50%	Other catches - 50%
No change	26.77%	28.02%	11.90%	10.14%
Shift fishing grounds	39.37%	42.51%	46.83%	56.04%
Increase effort	19.69%	19.32%	11.90%	12.56%
Leave fishery	10.24%	6.28%	24.60%	17.39%
Decrease effort	1.57%	2.90%	3.17%	0.97%
Change gear	2.36%	0.97%	1.59%	2.90%
n	127	207	126	207

Community-level dynamics

The economics of MNF: supply and demand

Supply and fate of mosquito nets

202 households identified the source of their MNs. Of these 76% had received their nets as part of a free distribution or at a health centre, 17% had bought their nets and 6% had accessed nets through both means. Of the households who had bought all or some of their currently owned nets, 50% reported buying these nets in a nearby town and 50% from a trader coming to the village. Several households identified traders as coming from Tanzania, corroborated by two FGDs which reported that prior to mass distributions MNs for MNF were bought from Tanzanian traders. One FGD respondent claimed that private net sale (specifically for MNF) is a growing problem:

"*Nets are used on beds. The problem is not from the government but people selling them. You can buy as many as you want. The government tells them not to use them for fishing, but it is their prerogative to fish*." Male respondent, FGD Quirinde.

Forty seven of those who bought their nets were able to report the price paid for those nets, with an average price of 106.25 mzn ($1.7) from local towns (n = 23) and 100.75 mzn ($1.6) from traders (n = 24).

196 households reported the fate of nets once no longer fit for purpose (either fishing or sleeping under).Of these, 71% stated that nets at this stage of life are discarded, either thrown outside or burned (in the open air, usually on communal rubbish piles as no incineration facilities exist at or close to either site). Repurposing for alternative uses such as crop protection, drying fish or chicken coops were reported by 15% of households and just 3% claimed to have used old nets for fishing, supporting the assumed preference for newer nets that drives the narrative that MNF is detrimental to bed coverage. Single mentions were recorded of a) a net melted down and reformed as a hand line, b) net scraps used for malaria protection as a standing water cover, and c) one household claiming to have sold their nets to mosquito net fishers for repairs. 9% of households said they had never yet had a net become unfit for purpose which is reflective of how recently mass distributions have occurred in the region.

Trade in 'medada' from MNF

Trader interviews and FGDs revealed both local and external markets influencing MNF across all OSOL sites, the price of medada at these sites, and localised trade systems. Medada prices are very variable dependent on the season, location, quality of the catch and how it is sold which may be by weight

(usually dry) or as 'portions'. However the most consistent estimate was of 10-15 mzn ($0.25) per 'portion' wet, 20 mzn if the fish are larger. A 'portion' is generally a large double handful or a small plastic bag which are standard units in the region. Dry fish tends to be sold per kg at 25-50 mzn ($0.4-0.85, with the higher price in the dry season). Given additional risks of spoilage, fishers prefer to sell their catch wet. Larger fish are preferred and confer a higher price. Both traders and FGs reported an increase in medada price over time (Figure 5.12), and related this to declining catch alongside increasing demand.

There was no evidence in either trader interviews or FGDs of external traders paying a higher price than this, and indeed traders in medada are still few, therefore much of the MNF catch is reportedly sold locally. However, external sale is increasing. Trader 2, interviewed in Quirinde, specialised in medada, having identified this as an opportunity in 2012. As such he bought only dried fish and has several regular villages where he buys fish to satisfy a large external market. Trader 1, interviewed in Malinde, was a generalist buyer but increasingly bought medada, with a particular interest in shrimp catches.

These prices reportedly escalate quite quickly outside of the villages. Trader 1 claims to sell medada in a neighbouring landlocked district at 50 mzn ($0.8) per portion wet, 60 mzn ($1) dry. He sells in portions as some buyers are end consumers, but others are traders from Nampula province (bordering Cabo Delgado to the south) and other Cabo Delgado districts. Medada prices may be double what he pays by the time catch reaches Nampula province. Trader 2 also sells in different, landlocked, districts of Cabo Delgado (Mueda and Montepuez). Neither trader had any knowledge of organisations buying medada at their stage of the market chain; they only sold to independent traders.

Both traders claimed that trade from Nampula is driven by declining local catches and that many fishers have also moved north from this district. They also both expressed concern at increasing numbers of Tanzanian traders (though not fishers) buying catch in Cabo Delgado. The reasons given were that Tanzanian traders buy many local products including fish and are at an advantage due to access to ice and transportation, as well as use of Shillings due to Mozambique's extremely weak currency since retraction of aid (Chapter 1). Despite concerns for the long run, both traders said they will sell to Tanzanians when they can.

Perceived costs and benefits of MNF to local people

MNF was perceived by local people to have a number of positive and negative impacts, both directly on MNF households and indirectly on other households and the community at large. Overall, a very broad suite of topics was recorded in the household survey, coming from both households who engage

in MNF and those who don't (Table 6.8). Positive aspects conferred by MNF at the household level included accumulation of wealth (income and material goods) and social assets, as well as supporting food provisioning in a variety of scenarios. Negatives at this level related more to a lack of alternatives, alongside issues of reduced mosquito net coverage. At the community level a broad availability of food is appreciated, helping the village in general to do better. Negatives centred on the sustainability issues, causing conflict and perceived catch declines. In terms of environmental impacts very few positives were seen, though some respondents expressed the neutral impact of MNF on the environment, and negatives focused on juvenile capture and damage to the sea floor.

Exploring this in more detail with FGDs, respondents' perceptions of the positive aspects focused on the immediate food and income provision of MNF (and Chicocota) as a benefit but noted that indeed this could be seen as a negative "because we have no choice, the catch is not better and it is not a better activity, but we need it." Environmental risks were acknowledged by all FGs and there was generally a high level of awareness regarding the sustainability of MNF, with strong reflections on its impacts on the community's children's futures. Violent conflicts over the issue of Chicocota were reported in two villages (Lalane and Malinde), driven both by those engaging and those not.

"*If you talk about this [the men who use these nets] may come to kill you.*" FGD Lalane[1]

"*Men may come with knives if you have a problem with Chicocota*." FGD Lalane[2]

"*At first the community cut and burned the nets as we thought they were bad. We didn't know why [Chicocota fishers] came at first, but we didn't think the nets were useful to us*." FGD Malinde

When asked whether or not the respondents would like MNF to continue in their community in the household survey, 72% of nMNF households said they would prefer continuation (n = 93), compared to 49% of MNF households (n = 109) indicating that households not actively partaking in MNF see it as important in the future. However, contrary to this, when asked whether they would like their children to MN fish in the future 83% of nMNF households said they would rather they didn't take part in this activity (n = 99), compared to just 54% of MNF households (n = 110). This may indicate a reliance on the resource by the community as a whole, but unwillingness to be directly engaged. Conversely it may be that nMNF households perceived more options open to their children than MNF households.

When exploring alternatives to MNF in the household survey there was a strong tendency for nMNF households (n = 62) to state a desire for their children to exit the fishery for education (47%), with 21% wanting their children to stay in the fishery but not to utilise MNs to do so, and only 9.68% seeing agriculture as a preferred future. MNF households (n = 63) instead showed the strongest preference

for remaining in the fishery but utilising an alternative gear (40%), with education and agriculture viewed as roughly equally preferable (26% and 24% respectively).

FGDs reported that enforcement of rules was weak, though 43% of households claimed to be aware of formal regulations against the practice of MNF and of these 84% considered the rules to be appropriate:

"*Government officials come to slap wrists but don't actively enforce. We have a CCP [Community Fishing Council] but they don't do anything*." FGD Qurinde

Table 6.8 - Key perceptions of positive and negative aspects of MNF to individual households, communities and the environment from household survey.

		Food security	Economic	Health & social	Other
Positive	Impacts on household	• Allows purchase of staples (such as rice, xima, pasta, oil, salt) • Means we can have curry (more than just staples) • We can buy affordable fish from people who MNF • Brings food in the rainy season • We can get food quickly when we need it	• Means we can buy extras (dothes, housing materials) • I can buy kapulana for my business • Brings reliable income • We cannot afford Nhavo nets (1/4") so use MNs	• It has made fishing more easy than with kapulanas – the net is less heavy and we are less tired • Means we can afford to do ceremonies for our children	• I would like to have more nets • I like this gear very much but cannot get a net
	Impacts on community	• Helps single women feed their children • Provides food for vulnerable households • There are more opportunities for buying food • We can buy food in times of hunger • We can access food quickly	• It is good catch for the village • People can buy things to improve their lives	• There is less hunger • Children can have curry, not just xima	• I would like all of my friends to have MNs to fish with
	Impacts on the environment	• Nothing is wasted from this catch • MNF is fine just for personal consumption • There appears to be a lot of fish to take without harm	• There are no disadvantages as there were already no fish left	NA	• MNF (Kutanda) is not harmful like Chicocota, this is the problem • MNF doesn't cause damage like some other gears • MN fishers don't fish every day

Negative	**Impacts on household**	• Spoils our other catch as fish do not eat or breed	• It has come to a time where we have no alternative • It takes away our son's and grandson's futures • We have no factories to work at, our factory is in the sea • We wouldn't do it if we could afford better nets	• We get bad sleep because we do not have nets for our beds – rats and mosquitoes are bad for sleep • Should be for malaria protection • Should be for mosquito protection • This is not one of our activities, we did not do this in the past	• It spoils our nets, they do not last long
	Impacts on community	• Next year we won't have any fish • Sometimes people do not even eat what they catch • It sends the fish away • It is decimating our resources • When we go to the sea we find nothing, everything is dead. • Not good on a large scale	• The government come and take our nets or fine us • You cannot question people or they will say 'you don't understand, you have food and money' • The fish cannot grow to a more profitable size • There are too many fishers now • If everyone does MNF there won't be anyone to buy fish • The money is going somewhere else, not to our business	• "They can bring knives if we have a problem" • Disease is increasing • Mothers are told to go fishing, it is not their choice • It is done for a lack of food or money, it is bad that there is no alternative • People have to fish further away • MN fishers are stung by rays and bitten by other things	• People should be penalised more for MNF • It should be stopped, particularly Chicocota • There is more crime, people aren't at home and thieves come to their houses.
	Impacts on the environment	• People shouldn't MNF in the same place every day • It rips up the seagrass • It damages the coral • It kills juveniles that people do not even eat • It destroys the fish habitats • People are walking more in the water and causing damage	• Takes small fish and crabs • Eggs, plants and coral are thrown away as useless • Kills small sea cucumbers	• Mosquitoes are emerging more in the area • We fish tranquilly with MNs, it is the people with the Chicocota who destroy the environment	• MNF dirties the water

6.4. Discussion

Much debate around small-scale fisheries in recent years has focused on the management implications of understanding their roles as 'occupations of last resort' (open access resources that one might fall back on in times where there are few alternatives and which may lead to poverty traps), and/or 'banks in the water' (providing regular access to immediate returns like a cash machine and a potential entry point for pro-poor interventions) (Béné *et al.*, 2009; Onyango, 2011; Béné, 2003; Cinner, Daw & McClanahan, 2009). The portrayal of MNF, particularly in the media, has been of the former; a last chance activity for those in extreme poverty, positing that this can be the only acceptable justification for the trade-off of one's family's health against a short term monetary gain (Gettleman, 2015). However, in these admittedly extremely poor but mixed fishing/farming communities, MNF doesn't seem to quite fit the role of the last resort. The results of this study position MNF as contributing to potentially significant advancements for Cabo Delgado households. This is further underlined in Chapter 5 with respect to female access to the fishery. Perceptions of MNF are also very positive in relation to its role in development; as well as a spontaneous way of meeting daily needs there are numerous mentions of greater ability for people to buy things like school uniforms, invest in small businesses, engage with savings groups and enhance their agricultural capacity, e.g. buy seeds to diversify crops. Thanks to the accessibility of MNF it may therefore go some way to redress inequities across the community as a whole.

Are MNF households more vulnerable?

There is no clear difference in vulnerability between households engaged in MNF compared to nMNF households; neither poverty level, engagement in the wider fishery or access to opportunities are clear predictors of MNF engagement. However one consistently clear tendency supported by both the qualitative and quantitative evidence is an impact of gender on engagement in MNF, with MNF households having a higher proportion of women and FGDs largely focusing on the activity as one performed by women. The results presented here also support the findings of Chapter 5 wherein male engagement in MNF (Chicocota) is of significant and growing importance, if not currently as pervasive, particularly as a semi-commercial exercise, and should not be overlooked despite seemingly lower engagement rates.

MNF households also showed a tendency to engage in a larger number of occupations, which might indicate that it is engaged in as a part of an adaptive strategy to spread risk, however it may also reflect women beginning to diversify beyond natural-resource dependent occupations (see below). Either way, the magnitude of the difference is small and cannot be used as a clear sign of vulnerability. The fact that MNF households are also more likely to be resident households may be linked to access to

gear and does seem to refute local assumptions that migrants may be the cause of MNF introduction. The higher number of adults who are primarily fishers in MNF households seems of little value in discussions about vulnerability without a greater depth of understanding in terms of the economic bearing this might have.

Though the results of this chapter show little evidence of a difference in vulnerability between MNF and nMNF households, it must be recognised that the data presented are a snapshot in time. There is the possibility that MNF has enabled these households to keep up with other, less vulnerable households, and without the availability of time-series data this cannot be confidently asserted either way.

Do MNF households increase their exposure to malaria?

The household survey showed no significant reduction in net availability per person for MNF households, and indeed self-reported coverage rates (proportion of household regularly sleeping under a mosquito net) were significantly higher in MNF households. Though there may be some effect of over-reporting of these coverage rates, this is arguably a better measure of the potential impact of MNF on ultimate anti-malarial efforts, as available nets do not necessarily equate to utilised nets (Koenker & Kilian, 2014). The reasons for this are unclear, however trader interviews revealed that even when bought from a trader or local town MN prices rarely exceed 100mzn ($1.7), an amount that compares well to potential incomes from MNF and therefore represents a good investment. Additionally, the fact that more than ¾ of households obtained their nets for free despite a near 50:50 split of engagement in MNF indicates there may be an effect of oversupply for these households, so they still have nets available for fishing (Bhatt *et al.*, 2015b). Though a small number of households professed a desire for additional nets with which to fish, it appears there is a generally high availability of nets through these multiple means, and difficult trade-off decisions need not be made between mosquito protection and access to medada. These results also refute an impact on the health of the wider community, as self-reported coverage rates are high enough to maintain the 'mass effect' intended by insecticide impregnation of nets (Howard *et al.*, 2000), whereby mosquito mortality rates from those using nets may have a knock-on protective effect on those who do not.

Role of MNF in household livelihoods

The overarching picture of MNF and its role at both the household and community level within Cabo Delgado is a complicated one, with a spectrum of relative contributions being made to both incomes and subsistence. Fishing is generally perceived to be less 'important' than farming for incomes and food, which conflicts with some previous studies which have found fishers to highly value the 'immediate returns' small incomes associated with fishing compared to the 'delayed returns' larger

incomes associated with farming (Béné *et al.*, 2009). MNF is then seen as a component of fishing contributions, further decreasing its perceived importance, perceptions which are supported by a reportedly higher likelihood to abandon the activity (willingness to exit) than other gears. However, these are broad-scale perceptions of relative importance, which may belie the significance to resilience of both immediate and delayed income portfolios (Torell *et al.*, 2010).

These survey results, viewed holistically, lend a more nuanced understanding of importance of MNF to those directly and indirectly engaging, elucidating value in certain unique contributions to both subsistence and income. There is no clear correlation between household wealth and engagement in the activity as income declines are pervasive across the entire community. However, the perceptions of importance of MNF by local people suggest variability in the contribution of MNF that may not have been picked up by the population-level quantitative analyses here. Instead, MNF appears to be a malleable adaptive response to both the meeting of daily food needs, and the desire to do well in one's community, acting as a longstanding, highly adaptable (and reactive), and even reliable source of food and income within the household livelihood portfolio. Therefore MNF plays a role in all three of Dorward et al's (2009) livelihood strategies:

Hanging in

In the qualitative results MNF has largely been painted as a subsistence activity, with many households only selling their catch if there is surplus or in times of need. The perceived average household subsistence contribution is significant at 27% of overall fishery catch, which contributes almost 40% of total household food. However, the picture is more complicated than this. Although no difference was detected between MNF and nMNF households in income change over the last 5 years, the general trend was for household income to decline, therefore all sources of monetary income are likely to be of increasing importance. Indeed, the general perception conveyed was that although farming is still seen as the primary activity for many, MNF is a necessary safety net that they could not do without. To households struggling to meet basic daily needs MNF may play two dichotomous roles; direct consumption of medada by the household, or sale of medada to invest in staple foods (e.g. xima). This latter option may convey a trade-off of nutritional quality (fish) for quantity (starches) used in times of particular need, or may be a less extreme strategy to maintain contribution to different parts of the plate when sources fluctuate.

Despite FG respondents professing to having no other option than to engage in MNF, most households had other livelihoods contributing to income and food, as well as time commitments to farming activities, and often engaged in other fishing gears (Table 6.6). Instead, this professed lack of alternatives seems to relate to the support MNF incomes provide during the time-lags experienced in

farming. Cabo Delgado communities broadly suffer a 'hunger period' during the rainy season, usually January and February, related to time lags between harvests and insufficient agricultural crops to survive a year (Rosendo, 2016). This highlights a crucial role of MNF during the rainy season in weathering these periods as part of a mixed hanging in strategy, providing a 'bank in the water' (Béné *et al.*, 2009) in these periods, both as an income source for periodically limited agriculture-associated staples and as a direct food source.

Stepping up

MNF was reported by several focus groups to be more than just a way of meeting daily needs, and the potential income contributions of MNF can be significant; MNF households reported an average of 25% of their fishing income (which makes up 50% of their total income) being derived from MNF. Though it is appreciated that Chicocota and Kutanda activities are viewed differently with respect to income role, with the former being more of a commercial activity, there is not much evidence to suggest MNF in any form has become more important to household aspirations than traditional fishing or farming activities. Consequently, there is evidence that the incomes generated may rather be used to invest in both legal fishing and farming activities. Women professed a desire to own formal gears, namely a 'Nhavo' net used for targeting shrimp which is more profitable than medada. For women, who are marginalised from other forms of income generation, MNF may be their only means of accessing the formal fishery, though none of the respondents professed to having done so yet. Men and women also stated use of MNF income for purchase of agricultural enhancements, tools and seeds. These investments in concurrent activities suggest MNF can be important for stepping up.

Stepping out

Further to contributions to existing activities, some households, and particularly women, indicated that MNF incomes directly contributed to an increased ability to invest in savings groups (VSLAs), small businesses (such as selling kapulanas or baking bread) and purchase of opportunity enhancing items such as school uniforms. This accumulation strategy is perhaps the most telling potential application of MNF income towards the perception that MNF helps people to 'do well' (Table 6.8). Additional to these economic applications, there were also indicators that MNF income may be used for household wellbeing improvements such as house materials, furniture or improved cooking stoves (which additionally serve to reduce time poverty (Rehfuess, Mehta & Prüss-Üstün, 2006)). An important response which should not be overlooked was recognition that MNF income enabled families to perform religious ceremonies for their children which can have significant positive social impacts for them, though specifically marriage for very young women (girls) can of course be detrimental in terms

of future opportunities (Kawarazuka *et al.*, 2017). These lifestyle improvements were seen to improve a household's standing in the community and serve as a form of stepping out in terms of social assets.

In terms of the initial decision trade-offs, between selling or retaining catch, the variability of FGD responses suggest a poverty spectrum may be inferred where households doing particularly well might sell their medada and consume their own high quality catch. Those households doing quite well may sell their high quality catch and retain medada catch for their own consumption. Those households not doing well may sell all their catch in order to buy staples. Households may not necessarily strictly adhere to a single strategy and these decision trade-offs are additionally influenced by fluctuating catch size, seasonality, local and external markets and food/income from other gears or occupations. For example; the reduction in consumption of medada in the dry season, for both MNF and nMNF households, can probably be attributed to reduced supply rather than demand for medada, both because of reportedly lower catch rates during these months and also a decreased time commitment to MNF in important agricultural periods. As I explored in Chapter 5, it is believed that the rainy period also yields better MNF catch; this variability is less apparent in the wider fishery (Samoilys et al., 2018, in press) which potentially further increases MNF's relative importance during the rainy season.

More than just food security; role of MNF in nutritional security

The reported contribution of MNF to households, when retained and consumed or bought as part of any strategy, is also likely to be disproportionately important in terms of nutrition, not just as a reliable source of protein. As I have explored in Chapter 2, small fish eaten whole are of considerable importance for micronutrient provision (Kawarazuka & Béné, 2011; Thilsted *et al.*, 2013, 2014), particularly for children (Bogard *et al.*, 2015). Chapter 5 has shown the overwhelming majority of MNF catch to be fish of less than 10cm (Figure 5.20) which are prohibitive in terms of time and effort to gut, meaning they are highly likely to be cooked whole, supporting these theories. Cabo Delgado currently suffers from the highest rates of malnutrition and stunted growth in children in Mozambique (Lopus, 2015) and farming has declined both in quantity, quality and diversity of crops for numerous reasons (Osbahr *et al.*, 2008; Riddell & Rosendo, 2015), including climatic change which is predicted to worsen considerably in coming years (Jones & Thornton, 2003). This means the predominant crops of maize, cassava and to a lesser extent rice (Payongayong, 2006) are likely not to be providing anywhere near the nutrients necessary for healthy diets. Even when consumed relatively infrequently, such as is the case during the dry season, medada consumption events may be important; small fish tend to be shared more equitably in the household, benefitting vulnerable women and children year-round in societies such as Cabo Delgado, where men may consume the majority of the more desirable foods (Thorne-Lyman, 2014).

The provision of a high proportion of overall household needs in the form of small fish eaten whole is likely to convey a significant nutritional advantage, further highlighting the importance of MNF to the wellbeing of these communities. Additionally, the benefits of MNF were also regularly associated with the ability to eat 'curry' (Table 6.8); this implies that a meal of more than just staples is cooked when medada is used, with vegetables, spices and stock used presumably to flavour the stew, which would probably not be used otherwise in a meal of, for example, cassava. Meals such as this improve overall dietary diversity, as well as enhancing mineral bioavailability and absorption from other foods in the diet (Thorne-Lyman, 2014).

Whether MNF in Cabo Delgado is just plugging gaps or providing opportunities for people to improve their lives, the general consensus is that it is an entrenched and important part of livelihood portfolios. This indicates that MNF is a part of community-wide resilience to current and future socio-economic change. As these chronic low-income situations persist and potentially increase, particularly from declining farming incomes and negative influences of globalisation, there is some potential for a changing role of MNF in to the future, with dependence on the activity increasing.

What does MNF mean for the wider community?

A. The benefits

An affordable source of fish

Whilst the results here show a significant difference in medada consumption between MNF and nMNF households, confirming an advantage in terms of access to this important source of nutrition for those who actively fish it, the rate of consumption for nMNF households is still of significance. MNF provides these families with fish for around half the week in the rainy season (and hunger period) and 1.5 days per week in the dry season (Table 6.5), indicating it is an important regular source of animal-based nutrition for everyone in the community, not just MNF households. For some, the seasonally reduced consumption may be out of choice as they may have access to other fishery resources, but for others it may be supply driven or down to ability to purchase medada. MNF's importance as a fish source was corroborated by local perceptions that medada has filled an important niche of an affordable source of fish for those who may not otherwise be able to afford 'better' catch (Table 6.8). Indeed, for some households which engage exclusively in farming this may be their only access to this form of nutrition. S. Rosendo (unpublished data) performed an investigation of overall sources of food in the OSOL sites as part of the project, which found that a high percentage of households in this region purchase the majority of their foods and that there is decreasing reliance on household production; the average contribution of purchased foods in mainland communities being as high as 86% in the village of Nsangue Ponta. Rosendo found that Quirinde and Malinde had the highest levels of self-production of

food in the study area, at 51% and 61% of total consumption respectively, but that purchase of food was still high and demand for cheap food sources was very high.

Interviews with traders also alluded to wet MNF catch largely being retained and sold locally, whereas catch from other gears that is considered more valuable is more likely to be sold outside of the villages in large towns or cities, or even exported out of the province to inland communities. This information is corroborated by research in the village of Lalane where the Sustainable Poverty Alleviation from Coastal Ecosystem Services (SPACES) Project, based at the University of Exeter, have performed a fuller market chain analysis for small mixed reef fish (Crona & Arton, 2017). That research found women's catch to be uniquely retained within the village, whereas men's catch was routinely transported to Mocímboa da Praia and beyond. The ability to easily dry medada, due to its small size, also led people to report that dried surplus catch can mean additional availability in the dry season where priorities for food production switch to agriculture.

Influence of trade – beyond fishing villages

The ability to dry surplus catch is a double-edged sword for locals as it enables trade of catch outside of villages; prices may be higher with access to a larger market, but the provision of a cheap local source of food may be reduced if catch is preferentially sold externally. Advocates of a better appreciation for the importance of small fish to national and international development, both in terms of trade and nutrition, have posited the ability to dry, transport and store these fish as critical to meeting the nutritional needs of non-fishing communities (e.g. Kolding & van Zwieten, 2011; Kolding & Zwieten, 2014; Thilsted *et al.*, 2014). Trader interviews revealed that there is indeed significant demand for dried medada both further inland within Cabo Delgado, but also in other provinces including the nationally important fishing province of Nampula to the south, where catches are reported to be declining drastically (Jacquet *et al.*, 2010).

Medada may be an extremely underappreciated and under-researched source of nutrition for a very wide geographic area and consequently of real importance to the food security of Mozambique as a whole. Demand was even reported from Tanzania to the north, where purchasing power conveyed by use of a stronger currency is much higher and where similar local declines in fisheries resources have been seen (Jiddawi & Öhman, 2002) and further exacerbation of demand is possible. Impacts of trade have important implications for development interventions where actors may seek to capitalise on medada provision and enhance trade chains outside of communities. These changes would need to convey a community-wide advantage, particularly to the poorest who may become unable to compete with prices driven by external demand. As I explored in Chapter 4 where the potential for animal feed companies to increase demand for MNF was suggested, so too could this external human demand.

Whilst I have questioned the umbrella consideration of MNF as unsustainable, at high and increasing levels any kind of exploitation may become unsustainable and also inequitable. Serious consideration needs to be given in future research as to the threshold where the benefit of such a source of fish to inland communities may become a risk to both long term sustainability and to the fishing communities so closely tied to marine resources.

Gender and social equity

From both the results presented here and those of Chapter 5, it is clear that MNF in Cabo Delgado is dominated by women. MNF households have a higher proportion of women and the combined efforts of MNF and gleaning (also a female-dominated activity) make significant contributions to overall incomes and subsistence (up to 60%). Therefore female fishing activities make an important contribution to overall household daily needs and wellbeing. This aligns with a surge in recent research seeking to re-evaluate the importance of women in fisheries, as they have been traditionally ignored for both monitoring and management efforts (Kleiber, Harris & Vincent, 2015). This has additionally significant benefits to female-headed and exclusively female households, which may struggle to overcome cultural barriers to income and food sources. Added to this, as I have discussed further in Chapter 2, other studies have highlighted the potential for female-provisioning in all household structures to disproportionately benefit nutrition, particularly for children, and for income to be spent on long-term wellbeing improvements such as education and housing improvements over short-term gains (Thorne-Lyman, 2014; Ranis, Frances & Alejandro, 2000; Harper *et al.*, 2013). Medada or alternative food sources bought with MNF profits by women may therefore be disproportionately benefiting vulnerable household members and contributing to overarching development at the community level.

Households also reported a slightly lower time investment relative to income and subsistence contributions for MNF compared with other activities, suggesting MNF pays off well even if overall less time is spent engaging in it. FGDs and general perceptions often described MNF as a reactive activity to shortages, or one which could be easily slotted in to a day around other commitments, perhaps providing a quick meal at the end of a farming day. These types of activities disproportionately benefit women who are typically time poor due to childcare and housekeeping duties (Bennett, 2005) and may struggle to commit to activities which require a larger investment of effort. Whilst farming constitutes a larger time investment, the tendency is for women and/or men to spend the day on their plot of land, where children can join them and they can cook meals in situ. At times this may also be necessary for pest management. Although this works logistically, this time is then spent siloed within household groups. An additional advantage of MNF to women was discussed in FGDs as 'social time' which may

be of great benefit to women's wellbeing: spending time with their peers and socialising whilst providing for the household. However, this has potentially more far-reaching implications in the formation of women's co-operatives, the development of their own economics and agreements in splitting the catch, trade and investment in equipment/expansion of their operations. Though this is not explored further in this thesis, such co-operatives may provide entry points for pro-poor interventions and have been shown to be more successful in this sense than male-dominated patron-client type arrangements (Basurto *et al.*, 2013). Pro-poor impacts are also provided by MNF-enabled engagement in savings groups for women. Additionally, women's enhanced role in fisheries from the introduction of such co-operatives could promote better inclusion in co-management efforts such as fishing councils, serving to build confidence and enhance social equity. These opportunities are few for women in the conservative communities of Cabo Delgado, where women are still limited to roles of lower social value (Wosu, 2018, 2015).

B. The risks

Growing conflicts and the effect of enforcement

FGDs revealed conflict over MNF issues, largely related to the male activity of Chicocota, which is considered more environmentally damaging and therefore more taboo (see also Chapter 5). These conflicts are reportedly even violent, something which was experienced directly by the research team. There is also an undercurrent of disapproval from a portion of the population towards MNF in general, though open conflicts between female fishers and men of the wider fishery do not appear overt. Men instead focused displeasure at itinerant fishers from outside of the village, often from Nampula. The household survey showed very few of the surveyed migrants to be MNF households, and indeed the research team saw no evidence of migrant households engaged in MNF during the life of this investigation. It is therefore perhaps unfair to blame the introduction and subsequent tensions involved in MNF solely on migrants who appeared to utilise generally better fishing gear compared to local households. However, this misplaced anger is not uncommon within artisanal fisheries, where outsiders often bear the brunt of negative perceptions particularly if they are perceived to have better access to resources (Rosendo *et al.*, 2011; Crona & Rosendo, 2011).

Whatever the cause of the spread of Chicocota, it is unlikely that current tensions will ease as fishery resources become scarcer. MNF has been illegal in Mozambique since before the inception of the OSOL project and regulations have escalated from standard fines to a potential prison sentence for those convicted (IIP provincial director, Pers. Comms.). It is therefore likely that conflicts between fishers and enforcement agencies may also increase. Where this enforcement is carried out by local fishing councils one can foresee significant conflicts of interest for all involved. Anecdotal evidence from the

OSOL sites has indicated that authorities have on occasion prioritised enforcement against women, possibly because they are fishing inshore, easy to see and an easy target. From the results presented here it is obvious that simply to remove MNF as an option for this region with no alternative could have far-reaching negative impacts on food security and poverty traps. Prison sentences are clearly a disproportionate reaction to this problem, with potentially devastating consequences to households. Whilst this study did not explore the issue of conflict in more detail, it is clear that any effective interventions are going to need to understand the tensions better, debunk any false assumptions and advocate for interventions which are appropriate.

Influence of trade –medada and MN demand

Indications from trader interviews were that demand for medada is not being met, which has the potential to drastically alter the current economic position of medada and types of engagement in MNF in the future. Certainly one could predict that Chicocota might become the predominant MNF method of capture considering differences in CPUE (Chapter 5). Elite capture of profits through introduction of systems such as credit agreements, and capitalisation from roving bandit middlemen, moving from one resource to the next following depletion, may be a risk (Crona *et al.*, 2010a). The OSOL sites in general are currently screened somewhat from external influences by difficulties in access, particularly during the rainy season when some villages are completely inaccessible for significant periods. That said, Malinde and Quirinde are positioned closest to larger market towns and are likely the most influenced, particularly Quirinde which is also very close to the Tanzanian border. Interest in both of these villages was being shown by developers and traders until recently, with recent ice storage and transportation, a tourist lodge proposed for Quirinde and the recent introduction of an occasional 'Chapa' (informal bus) service to Malinde. Though these activities have been halted by the recent security situation in the region, there is potential for increased attention from traders and external influences in future.

What impact this could have is difficult to predict. Whilst some effect of increased market opportunities may trickle down to household incomes for MNF households, there is also potential for this to negatively impact local food security as a result of the localised-export of this cheap, local food resource. There would obviously also be additional incentive for more households to engage in MNF. This could lead to increasing pressure on the fishery, a relative dilution of incomes to current MNF households, conflicts and increased community-level vulnerability to catch declines. Disproportionate negative impacts would probably be borne by women owing to the tendency for predominantly female activities to be dominated by men once becoming profitable, for whatever reason, in heavily

androcentric communities such as this (Williams, Williams & Choo, 2002). The knock-on impacts to household nutrition and development could therefore be severe.

In a similar vein, these data have revealed an influence of external trade on net availability, with MNF identified as a driver of trade in nets. With many households having bought all or some of their MNs from traders and larger towns, there is a clear demand for nets independent of mass distributions. Some of these purchased nets were also reported to have originated in Tanzania, a country which has received significantly higher investment in mass distributions, so some concern may be warranted in terms of the potential diversion from malarial intervention efforts in the net source areas. The ability to access nets outside of mass and other free distribution efforts has a significant bearing on the ability of health organisations to react to the issue of MNF in the region.

Future research needs

This investigation provides a first baseline and contextualisation of the socio-economics of MNF, for which there has currently been no research. Though it focuses on one province, and two specific communities, it has broad implication for the questions researchers need to be asking within Mozambique as a whole, whilst also providing insights and a comparative study for future case studies in other districts, countries and regions. Critically, these results have supported some of the theories I presented in Chapter 2, where I posit a general oversimplification of the MNF issue as one of simply poverty and 'misuse' of donated nets, and where I question the use of blanket policies for management. I therefor list below some of the deeper understandings from this chapter that will be critical moving forward in addressing this issue further within Cabo Delgado, and also further afield:

- Income and subsistence contributions from MNF are clearly important, however the methods I used here are necessarily coarse. These data highlight a need to better understand the role of MNF, and importantly the opportunity costs that may be involved in management options, both for MNF households but also those dependent on medada as a food source, and the ultimate role of the resource in weathering hunger periods. Therefore finer-scale time series data of food and income contributions, using repeat visits which capture inter- and intra-annual variation is a crucial next step.
- A comparative diet analysis across different medada consumption rates would complement such fine-level data. For MNF households, this would need to capture the additional foods that income from MNF is able to purchase. It would be useful to use dietary diversity scoring at a broader scale matched with food diaries, and to use stable isotope methods (Valenzuela *et al.*, 2018) to confirm or refute some of the theories surrounding nutritional benefits of small fish consumption, including intra-household consumption and impact on children's health.

- A full market chain analysis for medada catch specifically from MNF would ensure a good understanding of both the economics of MNF catch trade, therefore enabling risks and opportunities to be identified for the future, and also the food security role of MNF to the wider region.
- No specific drivers of MNF emerged from the quantitative analysis, outside of those perceptions reported qualitatively, which were quite variable. Poverty and its location-specific underlying drivers are clearly part, but not all, of the picture. With one of the main risks of MNF interventions posited as forcing people into poverty traps, this needs additional investigation at the household level. In addition, there appears to be a village-level variability in engagement in MNF which is probably, at least in part, culturally driven. Recent research has shown a strong effect of both village and occupational group on perceptions of environment and governance in communities in Zanzibar (Gehrig, Schluter & Jiddawi, 2018), a potentially important aspect of MNF engagement trade-offs. Understanding what does and does not make an 'MNF village' will be of critical importance for tackling the issue, both with enforcement and alternative methods.
- Finally, the above investigations need to be conducted for a number of comparative case study locations. Existing data may be utilised to identify appropriate case study areas with which to capture the variability in drivers and roles of MNF (including variable social and fishery-related characteristics), such as I have initially identified in Chapter 4. Such an exercise would greatly enhance the outputs of some of the recommendations I have made in Chapter 3 and constitutes another justification for the critical need to identify key MNF-affected areas.

7. Discussion

Chapter 2 has outlined a conceptual model of MNF based on current orthodox theory, and additionally included alternative theories which may apply to the activity outside of the current narrative. Chapter 3 has then shown how policy responses may be developed in response to these various theories, explicitly recognising a need for further research. This thesis has aimed to lend further depth to this model, questioning a number of the processes and outcomes which I have outlined, alongside filling some of the critical gaps necessary to further inform policy-makers. Chapters 4, 5 and 6 present some empirical findings at the global and local level that both support and challenge a number of the assumptions made in Chapter 2. Figure 7.1 shows aspects of the model which have been investigated, and where questions may have arisen based on this thesis.

The assumed negative impacts of MNF on fish stocks, and therefore long term food security have been questioned in Chapter 5, where evidence was presented with respect to objective B ('using the case study of coastal Cabo Delgado, northern Mozambique, qualitatively characterise an MN fishery in depth; critically assessing the theorised impacts of MN fishing on coastal ecosystems and evaluate how MNs interact with other gear types'). The evidence suggests that overlap of resource use with other fishers, in terms of space and species, is less than expected in the presented case study. This assumption is further called in to question by what appears to be the unexpectedly selective nature of MNF in terms of species, linked to a highly gendered aspect of MNF which poses potentially very different risk factors associated with male and female engagement. This gendering is of further significance as I have confirmed importance of MNF to women and the potential for positive knock-on impacts to families and communities, both in terms of food security and wider wellbeing, though further research is needed before conclusions on health impacts may be reached. Added to these positive impacts, the results of Chapter 6 show that MNF plays more than a last resort role for the poor and is an important aspect of household resilience; potentially playing an important role in poverty reduction rather than poverty trapping. An impact on mosquito net bed coverage should not be assumed, as no impact of MNF was found in the case study location. These results have extremely important ramifications for policy development, further highlighting the need for cross-sectoral work to identify pro-poor solutions to MNF that may capitalise on the benefits of MNF rather than simply battling the assumed negative impacts.

Risks of MNF have also been identified, and discussions in the relevant chapters have highlighted where research should focus to begin to address these. Whilst the selectivity and resource overlap

assumptions have been challenged, there is support for a risk of significant and expanding fishing effort in MNF fisheries. The underlying driver of new markets was also identified as a significant possibility. Chapter 4 characterised MNF globally, to address objective A ('to characterise the current global use of MNs for fishing, from the perspectives of key stakeholders from the health and resource management sectors'). It revealed broad variability in how, where and by whom MNF is carried out, thus highlighting MNF as a highly context-specific issue which requires investigation at local levels to better elucidate any threat to long term food security. MNF use in intertidal and reef habitats which may be damaging has been identified as a risk for biodiversity, and there are implications for fisheries to consider also if nursery grounds may be utilised heavily. Conflicts do exist between user groups over MNF, and whilst these may largely be falsely based on the aforementioned assumptions of harm to the fishery, policy-makers need to be mindful of the potential to exacerbate frictions when designing and trialling interventions.

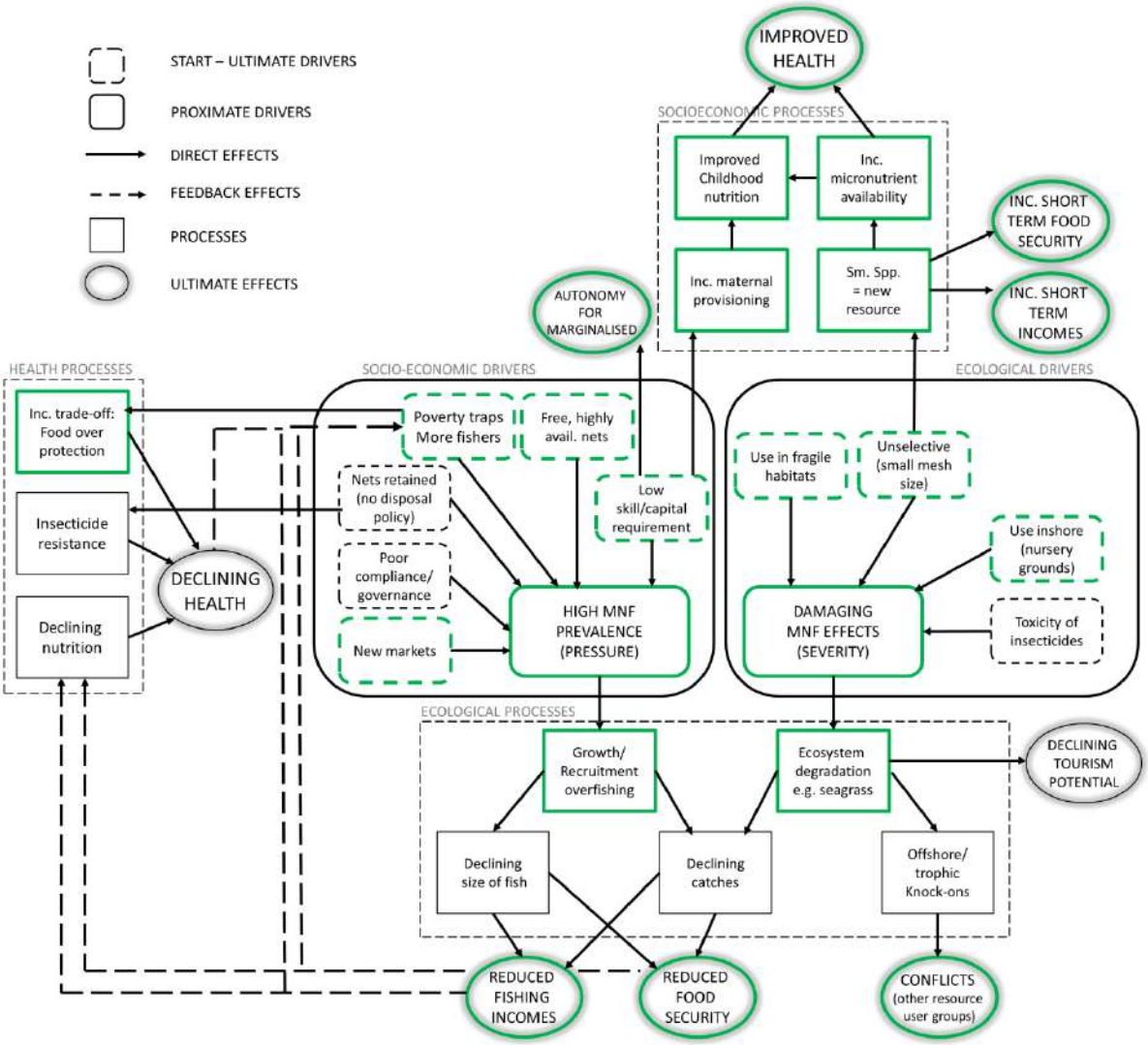


Figure 7.1 - MNF conceptual model with highlighted contributions of this thesis in green.

The contributions of this thesis have begun to build more of a picture of how MNF fits into socio-ecological systems and effectively sets the scene for further research, both at local and global scales. In this final discussion I will outline some of the broader, dominant and emerging narratives in fisheries, development, and health which have been identified as of particular relevance to MNF. I will additionally discuss how MNF may provide opportunities to expand these narratives and be utilised as a suitable case study for further research.

7.1 Is MNF the last resort of the poor?

The narrative surrounding the drivers of MNF currently is one of extreme poverty (Gettleman, 2015), positioning the activity as a desperate last resort which may enable a short-term weathering of food shortages, but which is ultimately a threat to long-term food security. The positive feedback effects of recruitment overfishing causing declining catches and growth overfishing meaning sub-optimal rents are assumed to be perpetuating poverty in affected regions, with some studies asserting that these impacts are already being felt (McLean *et al.*, 2014; Mulimbwa, Sarvala & Micha, 2018). In general, globally there is still a persisting view that these types of self-reinforcing, poverty trapped scenarios are best solved through interventions which aim to interrupt these cycles and increase incomes such as economic and/or technological injections to these communities (Carter & Barrett, 2006). For MNF the predominant response has been to make the activity illegal, aiming to preserve the outputs of the wider fishery through enforcement (Chapter 3) and presumably break the cycle of decline, despite the limited enforcement capacity available in the affected countries (Darkey & Turatsinze, 2014).

However, research into poverty has begun to extend beyond assumptions associated with poverty traps to incorporate resilience thinking; looking beyond assets to incorporation of political, social, economic, biophysical and historical influences which may help to solve or perpetuate poverty (Lade *et al.*, 2017). Resilience thinking is strongly aligned with socio-ecological systems research and applications (Adger, 2000); aiming to map the complex interactions between society and the environment towards effective management of people as part of a system; identifying opportunities to re-design interventions that aim to 'push' people out of poverty traps but that currently often fail (Ban *et al.*, 2013). In fishing communities this means looking beyond fishing as a Malthusian tragedy of overexploitation (Béné, 2003) engaged in by the poorest in society as an occupation of last resort; a notion which is increasingly challenged as research reveals the merits of an opportunity enhancement approach to fisheries over pushing alternatives (Onyango, 2011). Instead the role of fisheries in society needs to be considered in terms of all relevant socio-institutional factors such as health, education, access to capital, cultural inclusion, influence in institutions which control access (Béné & Friend, 2011; Allison & Horemans, 2006).

When approaching MNF from a resilience perspective a very different picture is painted to the one portrayed up to now. In Chapter 6, I investigated the contributions of MNF to households with respect to a variety of contributors to wellbeing, including incomes and how these are used in order to address objective D; to 'characterise how mosquito net fishing fits in to overall household livelihood strategies for fishers at the case study location, determining contribution of the activity toward incomes and food security'. Whilst there was evidence that MNF is used to buffer against extreme poverty, discussed in terms of Dorward et al.'s livelihoods framework as a strategy employed by those 'hanging in' (Dorward *et al.*, 2009), I also presented evidence that MNF offers opportunities to improve livelihoods and therefore influence numerous aspects of the aforementioned socio-institutional factors. The application of MNF to both 'stepping up' (improving productivity) and even 'stepping out' (facilitating alternatives) strategies positions it as much more than a last resort and indeed as a potential mode of exit from poverty traps. MNF is posited as causing fisheries declines, therefore being unsustainable, but in Chapter 5 I question this and apply the 'chicken or egg' question; is MNF rather an effective adaptive strategy to previously declining fisheries? When considering the suite of potential pathways out of poverty outlined in Lade *et al.*, (2017), MNF may be likened to a type I pathway; whereby the input of an asset (a free mosquito net) provides access to a novel resource, which is not necessarily short term, and enables the application of strategies to move the household out of poverty.

These results have highlighted a need to better understand the position of MNF within livelihood portfolios within and outside of the fishery (Béné & Friend, 2011), as there is currently little evidence that MNF serves as a standalone activity at the household level. I have also explored the role of MNF as a 'bank in the water' activity which is complemented by 'savings account' activities such as agriculture or seaweed farming (Béné *et al.*, 2009; Hill *et al.*, 2012), enabling the weathering of production time-lags, starvation periods or socio-ecological changes. This is true for both previous fishers experiencing yield declines, new entrants to the fishery owing to ease of use, and even those normally marginalised owing to cultural barriers. MNF is therefore of unappreciated importance to the reduction of the household vulnerability which can be experienced by full-time fishers (Béné, 2009).

In a critique of what is posited as the current narrow view of adaptive capacity, Cinner *et al.*, (2018) identify a robust approach to identifying and building upon such adaptive capacities in coastal communities. The focus in Cinner *et al.* (2018) was on adaptation to climate change, but their analysis is broadly relevant to regions experiencing socio-ecological changes of all types. These recommendations could be drawn upon to explicitly assess the current and potential contributions of MNF at the local and broader scales and so to lend a more balanced view of arguments for and against management options for MNF that seek to minimise harm to those utilising it to overcome poverty.

Below I adapt the questions from Cinner *et al.*, (2018), using the results of the Cabo Delgado case study to illustrate how they may be relevant to MNF:

- How does MNF influence ability to accrue assets, particularly monetary savings? In Cabo Delgado fishers identified a role of MNF in enabling engagement with VSLAs, particularly for women, as well as paying for travel to and costs of medical care and enabling the purchase of big ticket items such as household improvements.
- What is the role of MNF in flexibility between adaptive strategies? Certainly in Cabo Delgado it was identified that MNF is important in weathering regular starvation periods from agricultural time lags as well as acting as a potential long-term adaptation to overall agricultural decline. In a willingness to exit analysis MN fishers showed more variable responses, including a higher willingness to exit than those using other gears, and also professed to adapting their engagement in MNF to take advantage of seasonal fluctuations in juvenile fish numbers.
- Does MNF promote social organisation? For women in Cabo Delgado this was a significant benefit, being one of very few livelihood options open to women where co-operation with others is key to success. Fishing groups for Kutanda were informal arrangements of families, neighbours and friends from which economic and benefit sharing agreements were naturally developed. Households also reported that incomes from MNF had allowed them to do better in the community and bolstered social capital.
- Does MNF facilitate new opportunities for learning? Whilst this is not contextualised as well in Cabo Delgado, one might posit that a focus on new fishing methods, conducted in intertidal zones, and harvesting of new species may indeed provide new, shared experiential learning opportunities. For marginalised groups this is likely to be a strong influence, and engagement in a fishery not predominantly reliant on benthic, sessile species should broaden experience for gleaners in Cabo Delgado. For new entrants to the fishery, engagement in co-management efforts such as community fishing councils would enable access to learning about numerous levels of organisational and governance processes, but this is not currently open to MNF fishers because the gear is not recognised as a valid target for co-management.
- Does MNF promote agency (power and freedom) in a household's ability to adapt? For women in Cabo Delgado this is starkly demonstrated; MNF has circumvented many of the cultural barriers to engagement in the fishery and consequentially gives access to life-changing incomes and autonomy for food security.

7.2 MNF and food security; equity or disaster?

An important lesson from both the localised case study and the global investigation in addressing objectives A and B is that MNs are highly malleable as a fishing gear, with adaptations possible to suit many needs and environments. This makes them a broad-scale threat to biodiversity and means previous perceptions of a limit to their scale must be reconsidered, but also means that they can be adapted to the needs of the vulnerable and marginalised, thus contributing to social equity of fisheries. In Cabo Delgado I have shown MNF to play a central role in food security, both as a regular source for the poor or means of weathering starvation periods, and also as a potentially pivotal source of micronutrients. I have also demonstrated that previous assumptions of MNF as a highly unsustainable activity may not be true. Both the risks and benefits of MNF to food security make a compelling case for its inclusion in management, as opposed to the exclusionary blanket bans that are currently favoured. What this inclusion would look like still requires much thought and research; the hard question of whether or not management could or should involve some type and/or level of legitimised MNF is, in my opinion, not yet nearly well enough informed to answer, but should not be ruled out.

Despite recent advances in valuing the food security contributions of small scale fisheries (SSFs), some would still posit that there is an unaddressed trend of side-lining SSFs and re-focussing management attempts on decreasing reliance on wild-caught fisheries through aquaculture. Additionally, despite growing evidence of the potential for SSFs to provide key micronutrients to the food insecure (Kawarazuka & Béné, 2011), addressing the global micronutrient deficiency focuses on provision of supplements rather than utilisation of existing resources (Virot, 2007; Imdad & Bhutta, 2012). However, there is evidence that aquaculture is not always the answer in terms of food security, with limited large-scale success in Africa (and particularly Mozambique) (Bolton, 2017; Satia & Food and Agriculture Organization of the United Nations, 2017; Blanchard *et al.*, 2017); cultured fish in poorer countries are generally destined for middle-class markets elsewhere and may be inaccessibly priced for those in the production communities to afford, meaning aquaculture makes little contribution to local needs (Blanchard *et al.*, 2017). There is also the growing argument that aquaculture is inefficient in terms of feed conversion ratios, i.e. fish eat fish (Duarte *et al.*, 2009) and that significant trade-offs between wild-caught fisheries and aquaculture require addressing, particularly under climate change scenarios (Blanchard *et al.*, 2017). This last point has a particular bearing on MNF, whereby the types of fish caught may preferentially end up going to aquaculture (which evidence in Chapter 4 shows may already occur on some places) when a desire for direct human consumption already exists. So a contentious but potentially illuminating question would be whether MNF may be better incorporated into management and legitimately utilised as a direct sustainable food source, rather than illegitimately providing feedstock for aquaculture?

This thesis was never intended to be an empirical investigation into balanced harvest (BH) theory with reference to MNF. However the potential applicability of some of my findings to BH theory (fishing over a broad range of sizes and species rather than increasing size selectivity (Garcia *et al.*, 2012)), warrants discussion. BH has been posited as of particular relevance to mixed, artisanal fisheries which by their nature tend to harvest over a wide range of species (Garcia *et al.*, 2012). MNF serves as a case study wherein almost any size fish has an economic or wellbeing benefit (as evidenced in Cabo Delgado in Chapters 5 and 6). These benefits subvert one of the predominant criticisms of the BH model when applied to commercial fisheries; that catches do not meet market demand for large bodied fish (Kolding *et al.*, 2016; Pauly, Froese & Holt, 2016). When considering MNF as part of a mixed artisanal fishery harvesting across the size spectrum, it may fill a niche harvesting at the smaller end of this spectrum not filled by other gears. The fishery as a whole may then represent what is described by Zhou et al., (2010) as a responsible model of BH without implementing dramatic changes to exploitation patterns to cover this spectrum, the need for which is also posited as an institutional incompatibility when considering commercial fisheries (Pauly, Froese & Holt, 2016). In a recent assessment of an unregulated, open access fishery versus a regulated fishery on Lake Kariba, Zambia, Kolding *et al.*, (2015) empirically demonstrated for the first time that an unmanaged, 'unselective' regime utilising a large range of mesh sizes and gear types produced the highest yields compared to other management scenarios; with juvenile catch constituting an important part of catches but demonstrating the least impact on fish community structure.

Drawing on the results of Chapter 5 we can see some potential for MNF to also contribute to BH by harvesting from alternative species of minimal direct importance to the rest of the fishery. This is an extremely thought-provoking aspect of the MNF investigation and one that deserves more attention in light of potential for damaging and dangerous alternatives (such as cyanide and blast fishing or risk-taking behaviours) and increasingly alarmist enforcement policies. A recent study by Mulimbwa, Sarvala & Micha, (2018) looks at MNF activity on Lake Tanganyika in terms of potential lost incomes by harvesting larval individuals of *Limnothrissa miodon* before reaching adult size, concluding that it represented a significant loss of $2.1 million based on larval offtake. Though more interest in the topic (such as this paper) is positive, I would caution against managers making decisions based on studies such as described above, which does not consider BH-type dynamics, does not address the cause or effect question inherent in the targeting of fry as a consequence of an already declining species, or take in to consideration many of the underlying principles of population dynamics. Further research should look to elucidate the potential for BH at the local level where MNF serves to complete a spectrum of gears within mixed fisheries. An important question is whether the capture of many juveniles is more damaging or may contribute more to food security than the capture of just a few Big

Old Fat Fecund Female fish (BOFFFs) by a gear such as a speargun. Recent evidence on recruitment impacts shows it is pertinent for managers to ask these questions (Barneche *et al.*, 2018; Law & Plank, 2018).

7.3 Gender and fisheries; the case for better representation

This thesis has throughout highlighted the central importance of gender in MNF, particularly through the Cabo Delgado case study as a key finding towards meeting objective B, as well as through expert witnesses from numerous locations reported in Chapter 4. There is a growing appreciation in fisheries research of the crucial need to better understand gender in natural resource exploitation (Kleiber, Harris & Vincent, 2015), and particularly fisheries, in order to navigate inherent pitfalls for management. Gender marginalisation has been appreciated as an additional level of marginalisation on top of the fishery-wide issues which can perpetuate poverty (Béné, 2003) and the poor definitions of gender-specific fishing has led to exclusion of women from management (Harper *et al.*, 2017). As such, addressing the needs of women in management is increasingly seen as essential for development (Bennett, 2005). Indeed marine conservation projects have been accused of institutionalising inequitable access to fisheries and are seen to have failed due to missing gender issues, such as gendered spatial management which is restrictive to women (Baker-Médard, 2017). Inclusion of women is often not easy despite the well-meaning efforts inherent in co-management. Their engagement in management processes is often restricted by other time commitments (e.g. for childcare), the lack of desire and confidence to engage, and the lack of support to do so, particularly from their husbands who may not allow it (Agarwal, 2000). Initial efforts to include women in co-management efforts, for example, have also suffered from 'gender evaporation' whereby an initial level of engagement is lost over time as these barriers are not addressed in methods and training for staff (Harrison, 1997).

The gender and fisheries literature generally approaches the issue as one of gleaners, collectors and processors, which are the dominant female roles globally and which position women as 50% of the fishing workforce (Monfort, 2015; Weeratunge & Snyder, 2009). MNF promotes an increased level of female engagement in the extractive part of fisheries activities, which may pose opportunities to overcome social barriers, positioning MNF as a pathway out of poverty (Lade *et al.*, 2017). In Chapters 5 and 6 I additionally outline the potential for MNF to disproportionately benefit women, and for this to have potentially large positive knock-on effects on the wider community through improved nutrition and investment in wellbeing enhancements; women tend to work to feed a family whereas men work to make money (Harper *et al.*, 2017).

Building on the resilience analyses suggested above I would recommend research which explicitly incorporates gender analysis and consequent understanding of socio-ecological systems, drawing on recommendations outlined in Kawarazuka *et al.*, (2017). In their paper, Kawarazuka and colleagues recognise a failure to explicitly include the nuances of gender in socio-ecological systems research. They go on to suggest methods for better integration of gender theory and methodologies into wider analyses and to promote interdisciplinary engagement, which may be applied to MNF research. I would add the evidence provided in this thesis to recent calls for disaggregation of gender in fisheries monitoring more generally (Kleiber, Harris & Vincent, 2015) with MNF as yet another example of an ecologically distinctive, meaningful, and overlooked activity for which there is little data collection. With reference specifically to marine spatial planning, de la Torre-Castro *et al.*, (2017) highlight the importance of understanding women's roles across a generalised seascape (in a spatial analyses) in order to fill gaps in knowledge of the relative importance if different coastal zones to incomes and subsistence from areas and activities all too often ignored, or acknowledged only on paper, because they are infrequently used by male fishers. This results in androcentric management that perpetuates the inequities inherent in fisheries. MNF has a real relevance to these recommendations as an activity both linked to the intertidal zone, and also having the unique quality of mixed gender engagement, albeit with very different strategies (Kutanda vs. Chicocota); future research needs to explore the influences of current and future management scenarios across the gender divide in order to inform equitable inclusion of MNF.

In Chapter 3, experts across disciplines agreed that female empowerment and women-focused interventions were likely to play a key role in addressing MNF in future and ensuring win-wins across sectoral objectives. Such interventions could in part aim to diversify opportunities for women both from fisheries alternatives and enhancement of activities within the fishery; capitalising on the benefits of self-formed women's co-operatives, which have been shown to be highly successful compared to male-dominated patron-client type arrangements (Basurto *et al.*, 2013). Additionally, managers could incorporate any naturally formed spatial segregation between men and women, perhaps allotting exploited intertidal areas for the activities of the associated user group (MN fishers, not always women of course). Cabo Delgado is a good example of an opportunity to draw on the cultural changes MNF may bring in conservative, heavily patriarchal communities to further empower women and other marginalised groups. Other, legal gears which may better target some of the economically favoured species from MNF (such as shrimp) and which women in Cabo Delgado expressed the desire (and presumably ability) to use do exist and may provide an alternative to MNF. However there would need to be a system of exchange and the success of gear exchange programmes is extremely variable (Maina & Samoilys, 2011). In a case such as this, where ongoing access to MNs is necessary for malaria

prevention it may be all too easy to replace exchanged illegal gears, therefore gear exchange could easily lead to additional pressure. Access to alternative gears would likely need to be facilitated in another way, such as increasing income sustainability and enabling self-investment in new nets.

7.4 MNF and the One Health movement

The perceived driver of availability of nets explored in Chapters 4 and 6 does support the argument that mass distributions and the provision of free bednets for malaria control have had a significant role in the rise of MNF. In Chapter 6 I explored some preliminary evidence of trade in nets from regions or countries where supply from distribution programmes may be more reliable, in this case from Tanzania to Cabo Delgado. The global review of MNF (Chapter 4) suggests that a lack of a bednet disposal policy also plays a driving role. These results suggest that there is more to MNF drivers than merely subsistence and trade in fish, and therefore that there is more for public health bodies to consider in management of their net distribution policies. I found no significant negative impact of MNF on bednet use when comparing coverage rates between MNF and non-MNF households. This concurs with findings by Bush *et al.*, (2016) in Kenya and suggests that the availability of nets, either free or very cheap to buy, means the assumed trade-off between personal malaria protection and ability to fish is not as stark as has previously been thought. However, the relationship between MNF and human health is potentially far more complicated; being part of a complicated socio-ecological system involving biodiversity and its ecosystem services, access to natural resources, nutritional needs, the threat of malaria and various aspects of wellbeing that may impact one's physical health.

It is the rise in research focused on just such complicated feedbacks systems that has spurred the global One (or planetary) Health movement. Chapter 3 has highlighted the truly cross-sectoral nature of MNF and positioned management needs as currently disjointed, but ultimately unified across stakeholders. This addresses objective D of this research; 'to evaluate stakeholder expectations of the potential effects of management intervention strategies, holistically informing management through conceptual models of resources, research needs and policy options'. One Health recognises the interlinking of environmental degradation, globalisation and connectivity, and human health, drawing on and utilising multi-disciplinary socio-ecological systems approaches as a means of designing interventions for human health solutions (Zywert, 2017; Cumming & Cumming, 2015). The literature on One Health currently focuses largely on the impacts of environmental declines in ecological services that may influence aspects of disease spread, particularly zoonoses, air/water quality and the ability of ecosystems to help buffer against human-induced changes such as antimicrobial resistance (WHO, 2017a). Conversely, there is also a growing appreciation for how health interventions can enhance success in conservation through programmes which integrate basic health and family planning needs,

for example Population-Health-Environment (PHE) programmes (Mohan & Shellard, 2014). One Health advocates propose even deeper integration of programmes, positing that under scenarios of environmental degradation, expensive, high-technology biomedical models deliver cures but do not address drivers of disease, and are therefore likely to become unsustainable (Zywert, 2017).

Instead it is proposed that understanding human health as part of socio-ecological systems can provide longer term solutions which identify and control drivers of disease and other human health impacts such as food and nutrition security (Alders *et al.*, 2018). This requires an understanding of the social, economic (particularly poverty) and ecological processes (Ross, 2012). The assumed negative nutritional impacts of MNF on health, due to declining food security, have already been largely discussed and questioned in Chapter 5. Although this remains a present risk, it is possible that the micronutrient provision of MNF has just the opposite effect, with small fish being incidentally abundant in the very micronutrients that are key to malaria survival (Shankar, 2000), and are of particular importance to childhood development (Caulfield, Richard & Black, 2004). There is a potential for additional feedbacks between exposure to disease, physical fitness and fishing capabilities. Fiorella *et al.*, (2017) have demonstrated the positive feedback impact of poor health and debilitating diseases such as malaria on the prevalence of engagement in illegal fishing activities. Activities like MNF, which typically involve less time, travel and risk-taking (in terms of danger at sea rather than enforcement), may be preferable when in poor health. Malaria generally occurs more in areas close to freshwater bodies where there are plentiful resources for larval mosquito stages, meaning that fishing communities are more at risk of malaria, but which also means that distribution programmes may concentrate MNs in these areas. One could posit that increased distribution efforts near to fisheries resources may increase the likelihood of MNF. Additionally, a healthy water body may support enough fish to keep mosquito larvae numbers down through predation, but an overfished one may not (Louca *et al.*, 2009). The literature described above on links between fisheries and poverty applies equally to malaria and poverty; there clearly is an extremely interesting question here surrounding the nexus of potential poverty-health-resource feedbacks specific to MNF which deserves some targeted attention and which would benefit from in-depth empirical and modelling studies.

7.4.1 Implementing One Health policies; identifying the win-wins

In chapter 3 I explored some of the flaws in current policy pertaining to MNF and explored future policy needs. Importantly, this requires examining both current and novel potential interventions for MNF and evaluating whether they may present 'win-wins' across sectors, whether they may generate conflicts which need to be addressed, or whether incompatibilities exist which may not be reconciled.

Traditionally, conflicts have existed between environmental management and malaria prevention, following the broad-scale use of DDT for mosquito control, which has understandably shaped some perceptions of an incompatibility between the two goals. Similarly, traditional conservation methods reliant on the exclusion of humans have led to some perceptions of incompatibility between these goals and human development. However, the inception of fisheries co-management, the growth of One Health, and other similar movements towards more holistic management methods which explicitly include people and their needs as part of linked socio-ecological systems, are hopefully changing these perceptions.

In completing Objective D through the policy workshop, a number of potential management interventions were explored through expert knowledge elicitation of stakeholders using a cost-benefit assessment framework as shown in Figure 3.1. The results of this exploration are detailed in Table 3.3. This interdisciplinary analysis revealed some of the proposed solutions are likely to remain conflicting, such as increased use of larvicides which were identified as having deleterious environmental impacts. Other potential solutions, such as increased use of indoor residual spraying or spatial repellents, may feed well into calls from the health community to diversify anti-malarial efforts away from MNs by better utilising the current 'toolbox' (Killeen *et al.*, 2017a). This may reduce the number of MNs available, but may ultimately fail to address the underlying drivers of MNF and therefore would be unlikely to engender cross-sectoral co-operation. Similarly, altering MN design to enhance their fitness-for-purpose and/or discourage their use for fishing may prove a solution, but poses potentially insurmountable opportunity costs to current MNF resource harvesters. However, it should be seen as encouraging that the majority of interventions proposed by the expert group demonstrated some sort of win-win across sectors and target communities.

One excellent example of a win-win approach is the promotion of housing improvements which are not only a longer-lasting form of mosquito protection than bednets, but which ensure protection of entire households rather than focusing on individuals (Tusting *et al.*, 2015). The social wins from this intervention come in numerous forms from increased overall wellbeing, protection from weather extremes, increased security and safety for the vulnerable, reduced indoor air pollution and better educational success (Pillay, 2017; Trisos *et al.*, 2018; Haines *et al.*, 2013). Indeed, these effects may well serve towards meeting goals across the majority of SDGs. All of these socioeconomic enhancements may then have a further impact on malaria morbidity and mortality, demonstrating effective additionality on the initial intervention from even an intra-sectoral viewpoint (Tusting *et al.*, 2013).

Other solutions such as women's empowerment and diversification of livelihoods hold very obvious cross-sectoral win-win potential. In an MNF scenario, fisheries co-management can be seen as a potentially effective mode of implementing such change, where many such aspects of increased equity and sustainability are already employed in solving similar resource conflicts. Co-management would naturally lend itself to incorporation of health-focused goals by explicitly recognising the relevant feedbacks in SES analyses. However, it becomes difficult to ignore the potential role of BH in a co-management setting, with the compelling potential that MNF may hold for food security and livelihoods. Whilst the potential of BH is a growing area of research, there is danger in focusing on BH in response to MNF, given that the feasibility of implementing BH in a sustainable way remains very much untested. Small-scale fisheries management, even after the capacity-building inputs required for co-management, remains limited by resource allocation. Whilst it is proposed that in some such fisheries BH may happen relatively organically as different resource user groups systematically target across the available species, there remains huge risk in deregulating to allow this, and intensive monitoring and effective management would be necessary. It may be far better to spread focus across development of multiple interventions, particularly those identified by the expert group as being already proven in terms of cost-effectiveness and scalability.

Lastly, novel solutions such as recycling schemes (which could be facilitated by models similar to that of the NetWorks project where fishing net recycling becomes self-sustaining, http://net-works.com/) can be driven by engagement of the private sector. MNs which are no longer fit for purpose can be viewed as an opportunity not just by affected fishing communities, but also by businesses. In a climate where ocean plastics and pollution are at the forefront of the public and industry's minds, and corporate responsibility for this pollution is a hot topic in the media, MNs present a compelling focus for innovation potential. All interventions should, of course, be complemented by further relevant research and be subject to rigorous cost-benefit analysis, and context-specific evaluation of feasibility and the potential for unintended consequences.

7.5 Conclusions

MNF provides an interesting case study which may seem counter-intuitive to other One Health research foci, being at first glance an impact of health interventions on the environment. However when you analyse further it becomes clear that the complex feedbacks amount to much more than that. As such, MNF is a wicked problem (Game *et al.*, 2014) of quite a unique nature (perhaps a super-wicked problem). Acquiring the necessary understanding of linkages between successful management of MNF, human health, environment, gender, social equity and sustainable fisheries will require a collaborative interdisciplinary approach. Disciplines relevant to One Health and socio-ecological

systems research span sociology, economics, political science, ecology and conservation, physical and earth sciences and public health (Zywert, 2017; Galaz *et al.*, 2014; Alders *et al.*, 2018; Fabinyi, Evans & Foale, 2014; Nuno, Bunnefeld & Milner-Gulland, 2014). MNF is a contentious issue with numerous potential conflicts between sectoral responsibilities for policy and action which I have explored in Chapter 3; overcoming current divides will be pivotal in applying One Health concepts to both research and action. Chapter 3 of this thesis is the product of a first-of-its-kind cross-sectoral workshop, with representatives from a wide range of disciplines coming together to begin to address MNF in a space which endeavoured to leave the political and historical barriers at the door. This goes to show what can be achieved in bridging gaps between multiple forces for good who may hold conflicting views of ultimate goals. If we began to apply this and other lessons learned in this thesis to tackling this super-wicked problem, there may be greater lessons to learn from MNF that apply more broadly to delivery of the Sustainable Development Goals.

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Appendices

Appendix A. Chapter 3

Table A.1 Workshop attendees and affiliations

Dr. Prue Addison	Interdisciplinary Centre for Conservation Science, University of Oxford, UK
William Arlidge	Interdisciplinary Centre for Conservation Science, University of Oxford, UK
Dr. Robert Arthur	MRAG, UK
Sara Berthe	VectorWorks, Johns Hopkins University, US
Kitty Brayne	Blue Ventures, UK
Sofia Castello y Tickell	Interdisciplinary Centre for Conservation Science, University of Oxford, UK
Dr. Sarah Coulthard	Northumbria University, UK
Elizabeth Drury O'Neill	Stockholm Resilience Centre, Sweden
Dr. Nick Hill	Zoological Society of London, UK
Dr. Amy Lehman	Lake Tanganyika Floating Heath Clinic, USA
Peni Lestari	Wildlife Conservation Society, Indonesia
Dr. Lena Lorenz	London School of Hygiene and Tropical Medicine, UK; University of Edinburgh, UK
Dr. Kate McIntyre	Independent consultant
Prof. E.J. Milner-Gulland	Interdisciplinary Centre for Conservation Science, University of Oxford, UK
Dr. Helen Pates Jamet	Vestergaard Frandsen, Switzerland
Dr. Melita Samoilys	CORDIO East Africa, Kenya
Rebecca Short	Imperial College London, UK; Interdisciplinary Centre for Conservation Science, UK; Zoological Society of London, UK
Mxolisi Sibanda	Worldwide Fund For Nature (WWF UK)
Prof. Rick Welsh	Syracuse University, USA

Resolving a wicked problem: Development of cross-sectoral policy and practice on the use of mosquito nets in small-scale fisheries.

Definitions:

MN – Mosquito net. Here we are considering all mosquito nets which are provided as part of mass campaigns or continuous distribution systems and are therefore either free or subsidised for the end user. LLINs (long lasting insecticide treated nets) have their own specific issues which will be considered, but for the purposes of this conversation we are referring to all nets delivered to communities.

MNF – Mosquito net fishing. The use of mosquito nets as a gear in small-scale fisheries.

General roles:

1 – Chair of plenary discussions and facilitator for fisheries and development sector

2 – Overall facilitator and facilitator for health sector

3 – Facilitator for conservation group

4 – Note-taker for conservation group, guardian of the 'idea bucket'

5 - Note-taker for fisheries and development group, guardian of the 'idea bucket'

6 – Note-taker for health group, guardian of the 'idea bucket'

Me – Roaming – detailed note taker for plenary sections.

The space: We have two seminar rooms booked. Both rooms have a board of some kind (it's a blackboard in the larger room). We should also be able to use the OMS café space, but we cannot use the space immediately outside the seminar rooms as it disturbs the offices.

Groups:

Name	Group (sectoral)	Mixed 1	Mixed 2
Nick Hill	Conservation	1	1
Kitty Brayne	Conservation	2	3
Sofia Castello y Tickell	Conservation	3	2

Mxolisi Sibanda	Conservation	1	3
Melita Samoilys	Conservation	2	2
Peni	Conservation	3	2
E.J. Milner-Gulland	Development	3	1
Rob Arthur	Development	1	3
Will Arlidge	Development	2	1
Sarah Coulthard (skype)	Development	3	2
Elizabeth Drury O'neill	Development	1	3
Rick Welsh	Development	2	1
Prue Addison	Health	3	3
Sara Berthe	Health	1	2
Amy Lehman	Health	2	3
Lena Lorenz	Health	3	1
Kate McIntyre	Health	1	2
Helen Pates Jamet	Health	2	1

Catering: We have a buffet sandwich lunch both days and tea and coffee breaks in the morning and afternoon.

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DAY ONE

(09:10 – 09:30) Arrival– PIC forms signed by all

(09:30 – 10:00) Welcome and introductions – Introduction to team, workshop structure, outputs and housekeeping.

RS to do introduction, housekeeping and workshop structure/outputs:

Chatham house rule – no-one identifiable for the views or data they contribute, but attendee list will be published wherever workshop outputs are.

PA to do house rules and facilitation:

Respectful listening and working in groups. For every breakout group we will act as facilitators, so please pay heed to these people.

All views will be taken in to consideration and people will have equal time to talk.

The 'groan zone' – what to do?

The premise of the 'idea bucket' – there will be important things said which do not contribute directly to the tasks set. For expediency and considering we have much to cover in two days we will capture these in the bucket, but please then allow the facilitators to steer the group back to the task at hand.

EJMG to intro ICCS and OMS

Attendees to introduce themselves

(10.00 – 10.40) Introductory talks; Rebecca Short & Amy Lehman

Time for questions

If time introduce session 1 before everyone breaks for coffee (so they're ready for group work straight after the break)

(10.40 – 11.00) Coffee break

#1 (11.00 – 12.30) Exploring the impacts of mosquito net fishing

Aim: Understand variation in how different sectors perceive the importance of the relative impacts of MNF.

Key question: *What positive and/or negative consequences (with ultimate impacts on people) do your sectoral group feel may be attributed to MNF?*

1.1 In sectoral groups (50 mins) - attendees will brainstorm perceived impacts of MNF; these can be positive and negative (they should have a go at both – if shortly before the end they haven't spent any time thinking about the positives steer them to do so). Facilitators should steer the group away from the top level impacts such as increased poverty, decreased food security, increased malaria mortality and bring them down to impacts that affect processes associated with these (i.e. detail) e.g. recruitment overfishing from juvenile capture, decreased 'community effect' on mosquito population, increased market for 'trash fish', increased autonomy for women etc.

The group should aim to free-list impacts and then discuss the following to identify a subjective top 3 'most important' based on their expert judgement. These do not need formal scores etc – they are prompts to help people thing about the importance of some impacts. The most important should be to them as a sector, but in general they aren't being selfish here, any impact can be noted:

- extent (number of people impacted),
- geographical scale (local to global),

- timescale (long term or short term impacts, < or >5yrs),
- and severity (level of impact on people),
- a confidence score that is based on expert judgement of the available evidence where high = empirical evidence exists, medium = based on accepted theory, low = expert speculation. Any big issues with this scoring will come out in the wash during the report back but it will mostly be medium to low.

Set up: Brainstorming will be done on flip charts – I will pre-prepare some tables on the flip charts with columns to prompt for the above considerations (so you can make notes) and you can free-list down the side, although feel free to use post-its if it ends up working better. Mark impacts chosen as most important with an asterisk and nominate someone to report back (change up each time, not facilitator, to drawn people in to main conversation)

1.2 Reporting back in plenary (40 mins) – groups will report back on their perceived top 3 'most important' impacts which we will categorise as per below.:

- Economic
- Social
- Environmental
- Health-related
- Other

Set up: Reporting back will be done electronically. EJMG will add to ppt table – some will fit in to more than one category so we can add the main points in to Table 1 and I will make additional notes to one side.

Hand out: Background doc and slides

(12.30 – 13.30) Lunch

#2 (13.30 – 15.00) Exploring the drivers of mosquito net fishing

Aim: Understand how the different sectors may perceive and prioritise the main possible reasons for the rise of MNF.

Key question: *What do you perceive are the likely drivers of the decision for a person to use a mosquito net for fishing?*

NB – this decision context implies that anyone owning a net knows what its intended purpose is and the gravity of the consequence for not using it on one's bed, this may not always be the case so please allow for this in your thinking.

2.1 As individuals (20 mins) - firstly, individuals will have 20 minutes to write down all the things they perceive as drivers of MNF on post-it notes. They should be encouraged to think about their own experience, both carrots and sticks, things pushing them in to MNF and things attracting them to MNF, and to try to include social, environmental, economic and health-related factors as per their expertise (will all be on slide for briefing). This should be left fairly free and individuals can go for underlying drivers (such as 'poverty') but should be encouraged to also think about processes (proximate drivers) once more, (such as human migration, drought or impaired agriculture, increased demand for trash fish etc.).

2.2 In sectoral groups (60 mins – leave 10 mins for writing it all down to report back)

The groups will then reconvene for the next hour and take it in turns adding their drivers to a board (or the wall or whatever you want). Drivers can be roughly categorised in to (I will divide up boards in advance with tick column for carrot or stick):

- Social
- Environmental
- Economic
- Health-related
- Other

These categories are for future use in the write-up but different categories will be used in the reporting back (see below). As drivers are added, duplicates can be discarded in a gradual 'boiling down' by discussion. Once up facilitators will ask: "can you as a group think of any others?" Groups will think about which of these drivers are likely to be the most important (up to 5) - influential, the most geographically widespread, applicable to the most people, occur in most common contexts.

Set-up: Individuals will brainstorm on post-its before sectoral groups reconvene and combine their drivers on a wall or board (dependent on room). Facilitators will add and remove post-its. They will be set-up in advance but should be divided as per the above.

Hand out: Background doc and slides

(15.00 – 15.30) Coffee break

2.3 Reporting back drivers in plenary (45 mins) – groups will be asked to pick out their 'most important' drivers to report back initially (we will say up to 5 but can extend according to time). Whilst reporting back the plenary group will also think about sectoral influence and drivers will be categorised according to sector (health, conservation, fisheries mgmt., development). We can allow a fair amount of

discussion here with the time, so groups should be encouraged to justify why they think these are the main drivers.

Key question: *Which of these drivers do we have influence over?*

Set-up: Reporting back will be done electronically and categorised by sector as we go, some drivers may be influenced by more than one sector so as with the impacts we will add the main points to Table 2 recorded by EJMG on ppt and I will make additional notes on the side.

#3 (16.15 – 17.30) Objective setting

Aim: To define a set of objectives which may be used in framing policy decisions.

3.1 Setting objectives in sectoral groups (45 mins)

Key question: *What do you, as a group, ultimately want with respect to MNF? What would an ultimate goal/change for the future look like?*

The group should be asked the above questions and then allowed to brainstorm freely some objectives they think would represent a suitable outcome for MNF management. Facilitator prompts might include:

- Think about the worst case outcome and how you would like to see that avoided.
- What are the specific concerns you'd like to see addressed?
- What direction would you like to see it moved in?
- What would you like to see in the short (<5yrs) vs. the long term (>5 yrs)?

Here the facilitators need to focus the group on getting to an 'end' objective – a single overarching goal. They can do this using the 'why game' and asking 'why is this important?' of proposed objectives. Groups need to be selfish here and think about outcomes that are best for their group. E.g. for the Conservation group this may be 'securing healthy reefs where MNF occurs'. Then you can think about some means objectives that relate to your sector (some will probably have already come out in the discussion towards the end objective) e.g. halt fishing methods which are destructive to the benthos; ensure protection of inshore nursery grounds; halt recruitment overfishing of reef species etc. However, groups also need to think about which sectors need to be involved to achieve their objective and what their role might be.

Set-up: Objectives will need to be recorded by hand as there are too many groups to set up screens. However, there are two large boards available and the third group can use a flipchart to note down objectives. Final objectives need to be short statements with the sectors who have influence over its

delivery, but all discussions (i.e. means objectives) need to be recorded. Facilitators can be in charge of main objectives (ends or getting towards ends) and note-takers recording all others.

➔ Health examples: All nets distributed are utilised for their intended purpose. Universal coverage is achieved in all at-risk regions. All people in at risk regions are aware of how and why to use their net. No-one in at risk regions are using their nets for fishing. Malaria rates continue to fall (a bit too general – gone too far).

Hand out: I will be updating tablets with the output tables as we go (just a photo, which will currently have the impacts and drivers complete), one for each group so that they can be referred back to.

3.2 Final report back in plenary (plus debrief) (30 mins)

Each group presents their end objective, with cards on the table as food for thought overnight.

Set up: We will record these in a word doc

(18.00) – Dinner @ Turl Street Kitchen (if the group is small enough otherwise a pub)

Overnight I will list out all of the objectives, split them in to means and ends and discard any duplicates, aiming to boil them down to the predominant means and ends objectives.

DAY TWO

(09:10 – 09:30) Arrival

#4 (09:30 -11:00) Objectives and interactions

Aim: Assess the compatibility of different objectives and the groups' perceptions of potential sectoral policy interactions.

Key question: *Where do explicit interactions occur between objectives and sectoral contributions?*

Quick recap from yesterday (RS)

4.1 In mixed groups 1 (40 mins) – cross-sectoral policy interactions

Objectives that are consolidated from day one will be disseminated to group facilitators who can read them out to their new groups (these groups represent a mixture of sectors and academic/operational roles put together at random). Groups should have a very brief discussion about the objectives in general and what they think before thinking about explicit interactions (synergies and complimentary objectives) between them. This is where individuals can really introduce contexts from their own experiences and should be encouraged to do so. Again, long and short term is important here.

Set up: This will be an open discussion but I will number the objectives to make it easier to record - a matrix table would be too big and confusing. The aim is not to compare every objective with every other objective, but for groups to discuss their instincts as to how they feel objectives may fit together or not. The detail will be important here, so note takers will be busy. Main notes can be taken by adding post-its to a board – each post-it detailing an interaction between two objectives, or freehand on a board to allow arrowed interactions.

Hand out: List of objectives

4.2 Report back in plenary (50 mins)

Each group will be asked to report back one synergy where objectives compliment or enhance each other, one neutral relationship where objectives can be achieved in parallel with no perceived issues, and one inconsistent relationship where objectives may not be achieved together in certain contexts. An open discussion of any that haven't been noted down will follow.

Set up: Here we will use (Table 4) of the above up on the screen (with E.J. recording) to note down the main points (i.e. nature of interaction) with myself recording the detail from discussions.

(11.00-11.30) Coffee break

#5 (11.30 – 13.00) Interventions brainstorm

Aim: To document existing and potential novel interventions from the experts' experiences that may be used to achieve the objectives.

Key question: *What specific interventions exist (or are thought of now) which may be implemented or adapted to achieve the set objectives? What are the policy mechanisms by which they could be employed?*

5.1 In mixed groups 2 (50 mins)

Groups will now brainstorm specific interventions that may contribute towards the objectives – no idea is a bad idea here. They should be encouraged to draw from their experiences, the literature, each other. There will be a number of established actions that will come up such as behaviour change, education, co-management that sort of thing. These can be broken down and time spent dissecting (e.g. modes of delivery of behaviour change programmes; co-management specifically focussed on integration of women in to activities etc) – we don't really have time for that in this section so let people know the detail can be chatted over in the next section and move on. Allow individuals 5 mins

to brainstorm on post-its first. If you need to kick things off you can always start with 'outright bans and enforcement'.

We aren't telling people as we don't want to lead them, but as facilitators we believe that most of the suggestions will follow the 'policy directions' in the below diagram. Some of the interventions are quite broad, and others specific, hence the need to just get them listed and discuss details later. Alternatively, if things get really quiet you can use the below diagram as a prompt – I will provide print-outs but I would rather they weren't used. The only one of these that truly tackles the underlying drivers of MNF is the integrated development policies (which all of the sectors can influence) but it's possibly the one they will not get to – so a little nudge in this direction at some point is a good idea by asking 'how do we tackle the underlying stick factors?'.

Set up: I will list some key considerations in the slide as a reminder from the activities beforehand. Free-list these on a flipchart using post-its (or board but in this case you will need to make sure the note-takers are recording a portable copy to report back from). Transport all the post its for the next session where we will be grouping them. Unfortunately there might be quite a lot to write down so it might be best if facilitators note the headlines and note-takers the detail. Likely policy routes are:

- Fisheries management policies (community and high level separated)
- Distribution policy (inc. R&D)
- Disposal policy
- Alternative vector control policy
- Integrated development policy

Handout: *optional

*TAKE PHOTOS BEFORE REPORT BACK

5.2 Report back in plenary and theme (policy directions) (40mins)

Groups will report back three interventions each to start with and then have an open discussion on any that have been missed. This can go quite quickly and we don't need to go in to detail, just short qualifying statements for any that people think are unclear. We can group them with our pre-defined policy directions in mind but won't rigidly stick to this necessarily (so I won't make a table). We need them all reported back in order to theme them so will have to keep to time.

Set up: I think we will need to do this with post-its on a board so that we are able to move interventions around and theme them as we go. We can use the post-its directly from the brainstorm. As groups report back we will stick post-its together when they are similar in policy route. I will note these all down over lunch.

(13.00 – 13.30) Lunch break

#6 (13.30 – 15.30) Evaluate interventions

6.1 Self-nominated groups (evened up if necessary) (1 hr 20 mins)

Individuals will nominate themselves to a policy theme they are interested in exploring and the listed interventions within this will be evaluated (as best they can) as per the following criteria:

a. Which objectives are addressed by this intervention?
b. Which objectives could be hampered by this intervention?
c. What operational synergies might exist – interventions which piggy-back?
d. Scalability – what is the scope of scaling up, or does the intervention require localised tailoring?
e. How expensive is it likely to be?
f. What is the evidence for success of this intervention if any?
g. Are there any additional benefits?
h. Collaborative needs - which sectors are able to contribute? Who else would be needed?
i. Critical knowledge needs - what information is required at a national and local scale?
j. Pitfalls - what context-specific factors may hinder success?

Set up: Groups may have to facilitate themselves here somewhat, depending on how we split, but we can make sure each group has one of the facilitators OR one of the note-takers. I will provide each group with Table 5 printed out to record in, and the above categories defined – they should be small groups and capable of working to an A4 sheet. They don't need to fill in every single field, don't knows are ok. They are there to prompt the critique.

Hand out: List of objectives, Table 5, photo of interventions in their theme

6.2 Report back selected interventions in plenary (40 mins)

Groups will report back their highlights (with the main output being the completed evaluations) as per the activity Elisabeth did but as:

- If money were no object (what would you promote as policy if funds weren't limited)

- The fast (something we could start tomorrow – impact not a factor)

- The slow (something that would take time but would be high impact)

- A wildcard (something innovative if they have thought of one)

Set up: We will have Table 6 set up to record the above in a ppt

(15.30 – 16.30) Coffee with debrief and discussion of ways forward

What conversations do we need to be having?

Who do we need to be having them with?

How do we get this issue noticed by the right people?

Who would like to be involved with the policy brief going forward?

Thankyous and future timeline

(16.30) End

Appendix B. Chapter 4

Table B.1 - Predominant peer reviewed literature with mentions of MNF locations (as of start of 2018) used in global map of extent (Figure 4.2)

Reference	Juvenile catch observed	User group/s noted	Location	Marine/freshwater	Potential impacts	Potentially detracting from bed coverage?
Abbott & Campbell, 2009	Yes	Women and children	Namibia (upper Zambezi floodplains)	Freshwater	Insecticide pollution	-
Allan et al., 2012	-	-	Chad	Freshwater	-	-
Atkinson et al., 2009	-	-	Solomon Islands	-		-
Banek et al., 2010	-	-	Liberia	-	-	Yes
Bennett et al., 2012	-	-	Sierra Leone	-	-	-
Darkey & Turatsinze, 2014	Yes	Artisanal fishermen	Mozambique, Beira	Marine	Declining catch; Damage to benthos	-
Endebu et al., 2015	-	-	Ethiopia, Lake Zeway	Freshwater	-	-
Halafo et al., 2004	Yes	-	Mozambique, lake Niassa	Freshwater	Stock depletion	-
Hamerlynck et al., 2011	Yes	Women and children	Tanzania	Freshwater	-	-
Jiddawi & Ohman, 2002	Yes	Women	Tanzania	Marine	-	
Kimerei et al., 2008	Yes	-	Tanzania, Lake Tanganyika	Freshwater	Fishery collapse	-
Koenker et al., 2013	-	-	Tanzania, Zanzibar	Marine	-	-
Larson et al., 2014	-	-	Kenya, Lake Victoria	Freshwater	-	Yes
Loll et al., 2013	-	-	Senegal	-	-	-
Lover et al., 2011	-		Timor-Leste	-	-	Yes
McLean et al., 2014	Yes	-	Tanzania, Lake Tanganyika, DRC	Freshwater	Declining catch; Insecticide pollution; carcinogenic effects	Possibly - malaria rates unaffected

Minakawa et al., 2008	Not explicitly	-	Kenya, Lake Victoria	Freshwater	-	Yes
Mosepele et al., 2009	-	-	Botswana, Okavango delta	Freshwater	-	-
Mushagalusha et al., 2014	-	-	DRC, Lake Tanganyika	Freshwater	-	-
Nightingale Devi et al., 2013	-	Men, women, children	India	Freshwater	-	-
Okeyo et al., 2004	-	Men and women	Namibia	Freshwater	-	-
Pravin et al., 2011						
Quarcoopome et al., 2011	Yes	-	Ghana	Freshwater	Stock depletion	-
Siddique et al., 2013	-	-	Bangladesh	Marine	-	-
Silvestre & Federizon, 1987	Yes	-	Philippines	Marine	-	-
Sinha & Sinha, 2013	-	-	India	Freshwater	Stock depletion	-
Srivastava et al., 2002	-	-	India	Freshwater	-	-
Tietze, 2011						
Tynsong & Tiwari, 2008	-	-	India	Freshwater	-	-
Van der Elst, 2003	Yes	Women	Mozambique	Marine	Conflicts with commercial trawler fishery	-
Tweddle et al., 2015	-	-	Zambia, Malawi	Freshwater	-	-

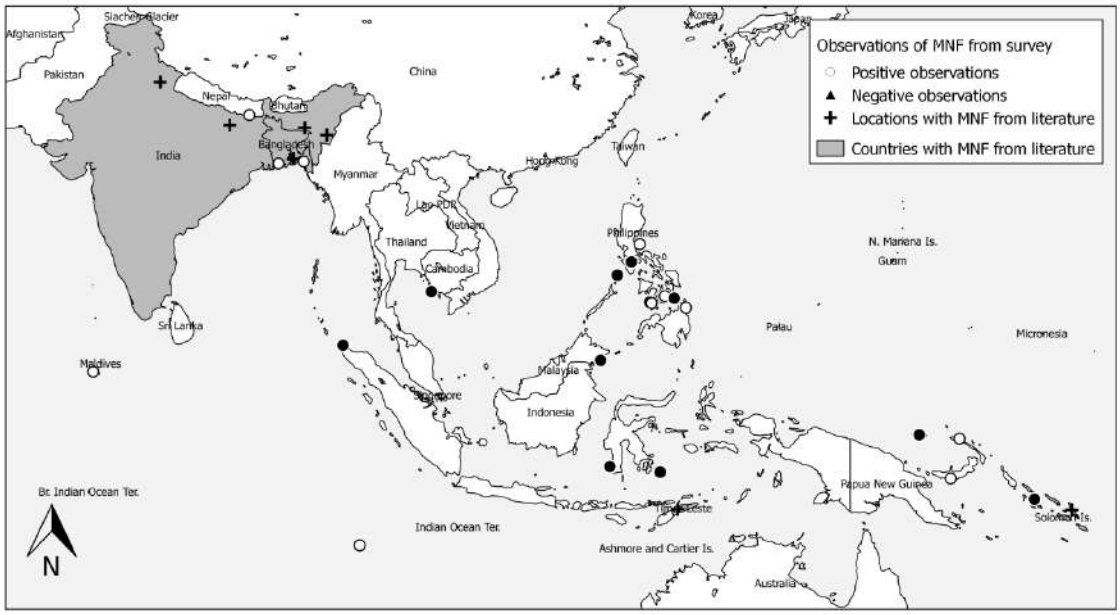

Figure B.2 - Map of survey responses in Asia and Oceania showing positive and negative reports of MNF

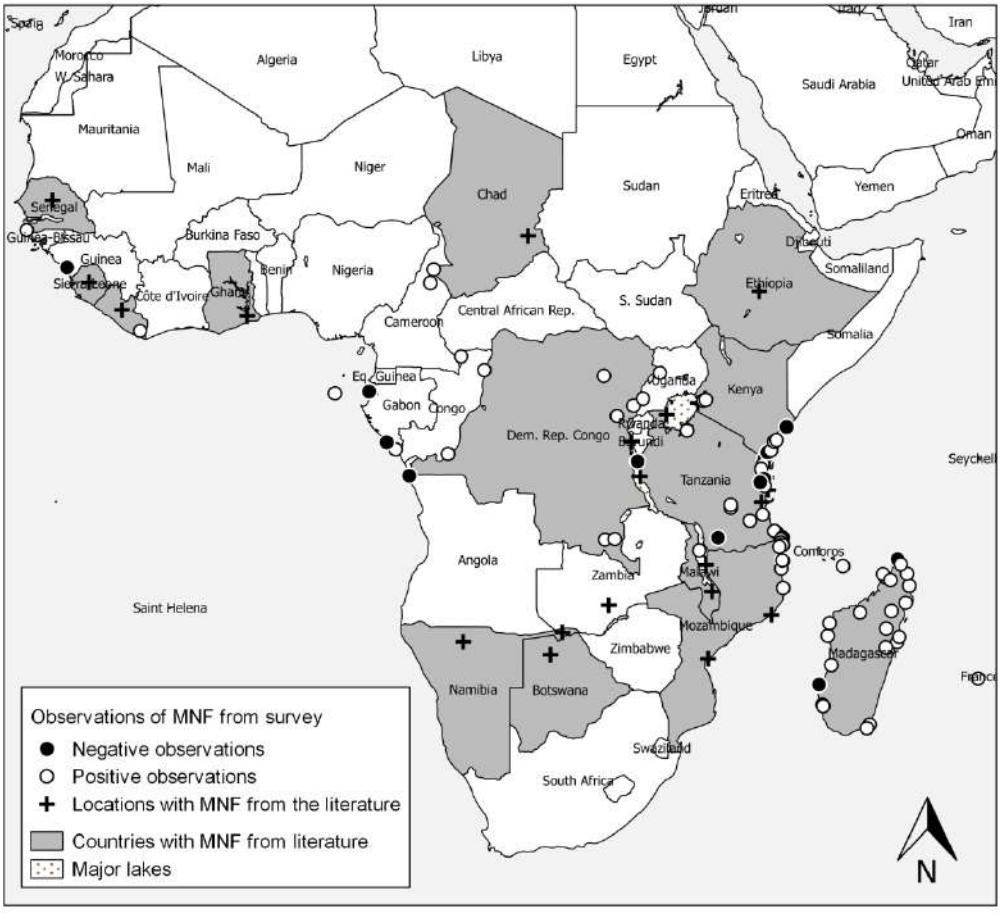

Figure B.3 - Map of survey responses in Africa showing positive and negative reports of MNF

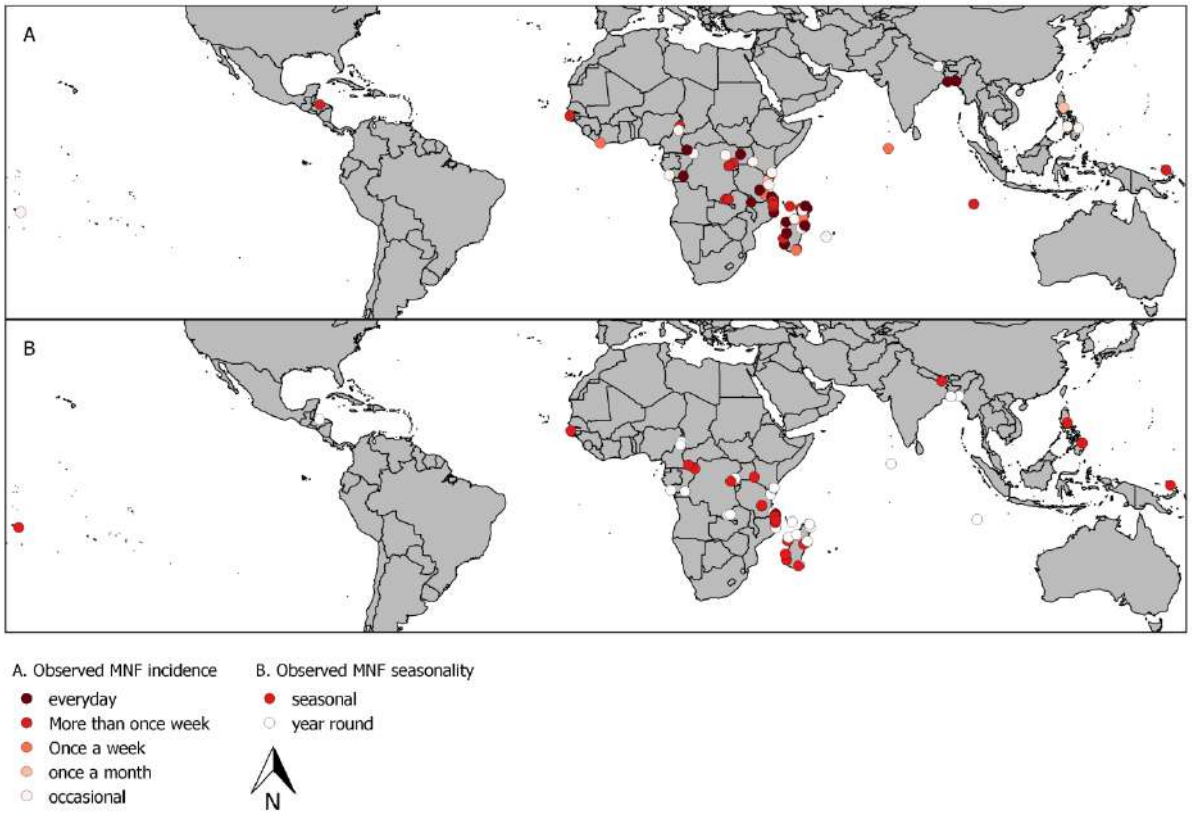

Figure B.4 - Observed global incidence frequency and seasonality of MNF from survey responses

Introduction to online questionnaire

Thank you for participating in this survey about the gears used in small-scale artisanal fishing in developing countries. We are particularly interested in the degree to which bed nets distributed for malaria control are being used in fishing in different parts of the world. There are two groups of people who we are targeting this survey towards, anyone who has knowledge of small-scale and artisanal fishing, and anyone who is involved in malaria control efforts in fishing areas of developing countries. We would be very grateful if you could complete the survey if you belong to one of these two groups regardless of whether you have observed bed nets being used in fishing because we are interested in both positive and negative observations of net use. The survey should only take about 15 minutes to complete and it should take less time if you haven't seen fishing with bed nets.

There have been a number of reports of bed nets being used for fishing, but these have been anecdotal or local. This study will give the first global perspective on the use of insecticide-treated bed nets and long-lasting insecticide-treated bed nets for fishing. This will increase understanding of the scale and methods of fishing with bed nets and its role in people's livelihoods so that we can provide advice on how to manage this growing phenomenon.

This questionnaire is part of an MSc research project by Rajina Gurung, from Imperial College London, in partnership with Zoological Society of London. The information you give will provide a valuable insight into this extremely poorly understood and documented issue. Your responses are anonymous and confidential, and general trends will be reported rather than specifics. We will be careful to ensure that our research does not harm local people in the areas of study, and that we maintain the highest ethical standards.

Are you happy to proceed on this basis?

- ☐ Yes
- ☐ No

Please specify which area you are most familiar with to take you to the relevant survey

- ☐ Small-scale and artisanal fishing
- ☐ Malaria control efforts

Survey targeted at individuals with knowledge of small-scale artisanal fishing

1. Country in which you are based:
2. Which country are you originally from?
3. Organisation:
4. Position:
5. Would you say your work is predominantly...

- ☐ Development focused
- ☐ Conservation focused
- ☐ Fisheries focused
- ☐ Other (please describe)

Please think about specific locations where you have had the opportunity to observe fishing practices for a substantial amount of time, either currently or in the past. The scale of location we are ideally looking for is at a village level but it could also be an area of coastline, river, lake, fishing location or a region. I will ask you to complete a separate survey for each location for which you feel able to give information

6. Please give the name of the location:

7. Country:
8. Type of location:
   - ☐ Coastal
   - ☐ Lake
   - ☐ River
   - ☐ Wetland
   - ☐ Other (please specify)
9. Location information
   - ☐ Size of location (please specify in km2 if known):
   - ☐ Lat/Long (if known):
   - ☐ Human population density (if known):
10. What kind of work do you do that takes you to this location?
    - ☐ Mainly field based
    - ☐ Mainly office based
    - ☐ A mix of field and office based
    - ☐ Other (please describe)
11. In which year did you start observing fishing at this location?
12. Are you still observing fishing at this location?
13. If no, for how many years did you observe fishing at this location?
    - ☐ 0-1 years
    - ☐ 2-5 years
    - ☐ 5-10 years
    - ☐ 10 years +
14. How well would you say you know the area and its fishing practices?
    - ☐ Very well
    - ☐ Moderately well
    - ☐ Not very well
    - ☐ Don't know
15. What are the predominant fishing activities in the area? Please tick all that apply
    - ☐ Commercial fishing
    - ☐ Artisanal fishing (for income)
    - ☐ Subsistence fishing (for domestic consumption)
    - ☐ Don't know

Picture A shows an untransformed bed net and picture B shows a bed net used for fishing. Nets made out of bed-netting have very small mesh size less than 3mm. Nets may be of variable shape, size and colour.

Picture A

Picture B

16. Have you ever observed fishing with bed nets at this location?
    - ☐ Yes (if you have photographic evidence please send images to email address at end of survey)
    - ☐ No

17. How frequently have you observed this happening, on average?
    - ☐ Every day
    - ☐ More than once a week
    - ☐ Once a week
    - ☐ Once a month
    - ☐ Occasionally
    - ☐ Other (please describe)
    - ☐ Don't know
18. What is the temporal pattern of bed net fishing?
    - ☐ Year-round
    - ☐ Seasonal (please describe)
    - ☐ Tide-dependent (please describe)
    - ☐ Don't know
19. In which of the following habitats have you seen fishing with bed nets? (Please select all that apply)
    - ☐ From the beach
    - ☐ At sea
    - ☐ Lake
    - ☐ River
    - ☐ Local stream
    - ☐ Coral reef
    - ☐ Seagrass beds
    - ☐ Mangroves
    - ☐ Other (please describe)
    - ☐ Don't know
20. How have you observed fishers fishing with bed nets? (Please select all that apply)
    - ☐ On foot
    - ☐ On a dugout canoe
    - ☐ On a sail boat
    - ☐ On a motorised vessel
    - ☐ On a commercial fishing vessel
    - ☐ Other (please describe)
    - ☐ Don't know
21. How are fishers using bed nets to catch fish? (Please select all that apply)
    - ☐ Use the bed net on its own to scoop fish out

- ☐ Sew the bed nets together to make a large fishing net
- ☐ Sew the bed net into the cod end of a larger fishing net
- ☐ Use the insecticide in the bed net to catch fish
- ☐ Other (please describe)
- ☐ Don't know

22. Who have you observed fishing with bed nets?

	Never	Sometimes	Often
Children	☐	☐	☐
Working-age women	☐	☐	☐
Working-age men	☐	☐	☐
Elderly	☐	☐	☐

23. Are bed nets predominately used by:
    - ☐ Experienced fishers
    - ☐ Part time fishers
    - ☐ Inexperienced fishers
    - ☐ Don't know

    Why do you think this?

24. What other occupations do bed net fishers have?
    - ☐ Fishing with other gear
    - ☐ Agriculture
    - ☐ Small business owner
    - ☐ Casual labour
    - ☐ Other, please describe
    - ☐ Don't know
25. In your opinion do you think people fish with bed nets…
    - ☐ For domestic consumption
    - ☐ To sell the fish
    - ☐ A mix of both
    - ☐ Other, please describe
    - ☐ Don't know
26. Which species are predominately caught in bed nets? (tick the main ones)
    - ☐ Reef fish (please specify main species if known)
    - ☐ Pelagic fish (please specify main species if known)
    - ☐ Octopus
    - ☐ Molluscs (please specify)
    - ☐ Crustaceans (please specify)
    - ☐ Other (please describe)
    - ☐ Don't know
27. Have you observed juvenile fish being caught in bed nets?
    - ☐ Yes (please describe how you know)
    - ☐ No
    - ☐ Don't know
28. Have you observed threatened or high value species being caught with bed nets?
    - ☐ Yes (please describe which species if known)
    - ☐ No
    - ☐ Don't know
29. Are you aware of any legal restrictions to the use of bed nets for fishing in this location?

- ☐ Yes (please describe, e.g. if legal or illegal throughout the year or at certain times of the year)
- ☐ No

If YES, are you aware of any active enforcement in the area and by whom?

30. Are you aware of any local customs or rules which relate to the use of bed nets for fishing?
    - ☐ Yes, please describe
    - ☐ No

    If YES, are you aware of any active enforcement in the area and by whom?

31. How do bed nets relate to other gears?
    - ☐ Used instead of existing gears
    - ☐ Used additionally to existing gears
    - ☐ Other (please describe)
    - ☐ Don't know
32. When did you first notice the use of bed nets for fishing?
    - ☐ They were already being used when I arrived
    - ☐ They came into use during my time at the location
    - ☐ Not sure
33. In what year did you first notice bed nets being used for fishing?
34. Do you know if there been any major change in prevalence of bed net use for fishing over time?
    - ☐ Yes (please describe)
    - ☐ No
35. Do you know what proportion of the population currently fish with bed nets?
    - ☐ Yes (please specify)
    - ☐ No
36. Why might a household choose to use bed nets for fishing (give up to 3 reasons)?
37. Why might a household not choose to use bed nets for fishing (give up to 3 reasons)?

Thank you so much for your input so far. Just a few short questions left on the distribution of bed nets in the location.

38. Have bed nets been distributed for malaria prevention in the location?
    - ☐ Yes
    - ☐ No
39. When was the last distribution of bed nets in the location?
    - ☐ Within the last year
    - ☐ 2-3 years ago
    - ☐ 4-5 years ago
    - ☐ 6-7 years ago
    - ☐ 8-9 years ago
    - ☐ 10 years +
    - ☐ Don’t know
40. Do you know who the last organisation was who distributed the nets?
    - ☐ Yes (please specify)
    - ☐ No
    - ☐ Don't know
41. How are nets reaching the area? Please rank in order of prevalence
    - ☐ Distributed at health clinics (please specify if distributed for free or at a subsidised price if known)
    - ☐ Distributed at maternity clinics (please specify if distributed for free or at a subsidised price if known)

- □ Distributed from government campaigns (please specify if distributed for free or at a subsidised price if known)
- □ Sold at local shops
- □ Sold from traders
- □ Received from relatives / family
- □ Distributed for free at schools
- □ Other (please describe)
- □ Don't know

42. Do you know what happens to bed nets after they are no longer usable for malaria control, in order of prevalence? (please select all that apply)
    - □ Thrown away
    - □ Destroyed by burning
    - □ Used for fishing
    - □ Alternative uses e.g. crop cover, wedding dresses etc (please describe)
    - □ Other (please describe)
    - □ Don't know

Contact email address or telephone number (optional if you have witnessed fishing with bed nets or have an opinion on the matter and would like to discuss further

Thank you very much for your time. Please use the space below to add any other comments. If you would like a copy of my results please specify in the space below and put in your email address if you haven't included it already. If you have any photographic evidence of fishing with bed nets, other information to share (e.g. relevant reports) or would like to discuss this further, please email me at: rajina.gurung14@imperial.ac.uk.

If you feel you are able to give more information about fishing practices in another location please select the 'yes, I have more information to give on another location' box to fill out another survey for a separate location. If you would like to end the survey please select 'no, I do not have any more information to give on another location.'

- □ Further comments
- □ Yes, I have more information to give on another location
- □ No, I do not have any more information to give on another location

Survey targeted at individuals involved in malaria control efforts

1. Country in which you are based:
2. Which country are you originally from?
3. Organisation:
4. Position:
5. Would you say your work is predominantly...
    - □ Development focused
    - □ Health focused
    - □ Other (please describe)

Please think about specific distinct locations where you have had the opportunity to observe bed net distributions or been involved in malaria control efforts in fishing areas of developing countries, either currently or in the past. A location could be a village, area of coastline / lake / river, fishing location or a region. I will ask you to complete a separate survey for each location for which you feel able to give information.

6. Please give the name of the location:
7. Country:
8. Type of location:
    - □ Coastal

- ☐ Lake
- ☐ River
- ☐ Wetland
- ☐ Other (please specify)

9. Location information
   - ☐ Size of location (please specify in km2 if known):
   - ☐ Lat/Long (if known):
   - ☐ Human population density (if known):
10. What kind of work do you do that takes you to this location?
    - ☐ Mainly field based
    - ☐ Mainly office based
    - ☐ A mix of field and office based
    - ☐ Other (please describe)
11. How long have you worked in this location?
    - ☐ 0-1years
    - ☐ 2-5 years
    - ☐ 5-10 years
    - ☐ 10 years +
12. How well would you say you know the area?
    - ☐ Very well
    - ☐ Moderately well
    - ☐ Not very well
    - ☐ Don't know
13. Have bed nets been distributed for malaria prevention in the location?
    - ☐ Yes
    - ☐ No
14. When was the last distribution of bed nets in the location?
    - ☐ Within the last year
    - ☐ 2-3 years ago
    - ☐ 4-5 years ago
    - ☐ 6-7 years ago
    - ☐ 8-9 years ago
    - ☐ 10 years +
    - ☐ Don't know
15. Do you know which brand of insecticide-treated bed net or long lasting insecticide treated bed net has been distributed or is prevalent in the area? (e.g. Olyset, PermaNet, Netprotect, Duranet, Inceptor etc)
    - ☐ Yes (please specify)
    - ☐ No
16. Do you have any information on the uptake (number of bed nets distributed) of bed nets from the last distribution campaign?
    - ☐ Yes (please describe)
    - ☐ No
17. Do you have any information on the proportion of individuals sleeping under bed nets in this location?
    - ☐ Yes (please describe)
    - ☐ No
18. If relevant, do you have any specific targets for uptake (number of bed nets distributed) and coverage (number of bed nets being used on beds) of bed nets?
    - ☐ Yes (please describe)
    - ☐ No
    - ☐ Don't know
19. If relevant, what is your organisations policy on disposal of old bed nets?
    - ☐ Replacing old net for new net
    - ☐ No disposal

- ☐ Self-disposal by recipient
- ☐ Other (please specify)
- ☐ Don't know

20. How are nets reaching the area? Please rank in order of prevalence
    - ☐ Distributed at health clinics (please specify if distributed for free or at a subsidised price if known)
    - ☐ Distributed at maternity clinics (please specify if distributed for free or at a subsidised price if known)
    - ☐ Distributed from government campaigns (please specify if distributed for free or at a subsidised price if known)
    - ☐ Sold at local shops
    - ☐ Sold from traders
    - ☐ Received from relatives / family
    - ☐ Distributed for free at schools
    - ☐ Other (please describe)
    - ☐ Don't know
21. Do you know what happens to bed nets after they are no longer usable for malaria control, in order of prevalence? (please select all that apply)
    - ☐ Thrown away
    - ☐ Destroyed by burning
    - ☐ Used for fishing
    - ☐ Alternative uses e.g. crop cover, wedding dresses etc (please describe)
    - ☐ Other (please describe)
    - ☐ Don't know
22. Where is this information coming from? E.g. own research, malaria indicator survey etc (please specify)

Picture A shows an untransformed bed net and picture B shows a bed net used for fishing. Nets made out of bed-netting have very small mesh size less than 3mm. Nets may be of variable shape, size and colour.

Picture A

Picture B

23. Have you ever observed fishing with bed nets at this location?
    - ☐ Yes (if you have photographic evidence please send images to email address at end of survey)
    - ☐ No

24. How frequently have you observed this happening, on average?
    - ☐ Every day
    - ☐ More than once a week
    - ☐ Once a week
    - ☐ Once a month

- ☐ Occasionally
- ☐ Other (please describe)
- ☐ Don't know

25. What is the temporal pattern of bed net fishing?
    - ☐ Year-round
    - ☐ Seasonal, please describe
    - ☐ Tide-dependent (please describe)
    - ☐ Don't know
26. In which of the following habitats have you seen fishing with bed nets? (Please select all that apply)
    - ☐ From the beach
    - ☐ At sea
    - ☐ Lake
    - ☐ River
    - ☐ Local stream
    - ☐ Coral reef
    - ☐ Seagrass beds
    - ☐ Mangroves
    - ☐ Other (please describe)
    - ☐ Don't know
27. How have you observed fishers fishing with bed nets? (Please select all that apply)
    - ☐ On foot
    - ☐ On a dugout canoe
    - ☐ On a sail boat
    - ☐ On a motorised vessel
    - ☐ On a commercial fishing vessel
    - ☐ Other (please describe)
    - ☐ Don't know
28. Who have you observed fishing with bed nets?

	Never	Sometimes	Often
Children	☐	☐	☐
Working-age women	☐	☐	☐
Working-age men	☐	☐	☐
Elderly	☐	☐	☐

29. How are fishers using bed nets to catch fish? (Please select all that apply)
    - ☐ Use the bed net on its own to scoop fish out
    - ☐ Sew the bed nets together to make a large fishing net
    - ☐ Sew the bed net into the cod end of a larger fishing net
    - ☐ Use the insecticide in the bed net to catch fish
    - ☐ Other (please describe)
    - ☐ Don't know
30. Are bed nets predominately used by:
    - ☐ Experienced fishers
    - ☐ Part time fishers
    - ☐ Inexperienced fishers
    - ☐ Don't know

    Why do you think this?

31. What other occupations do bed net fishers have?
    - ☐ Fishing with other gear

- ☐ Agriculture
- ☐ Small business owner
- ☐ Casual labour
- ☐ Other, please describe
- ☐ Don't know

32. In your opinion do you think people fish with bed nets…
    - ☐ For domestic consumption
    - ☐ To sell the fish
    - ☐ A mix of both
    - ☐ Other, please describe
    - ☐ Don't know
33. When did you first notice the use of bed nets for fishing?
    - ☐ They were already being used when I arrived
    - ☐ They came into use during my time at the location
    - ☐ Not sure
34. In what year did you first notice bed nets being used for fishing?
35. Do you know if there been any major change in prevalence of bed net use for fishing over time?
    - ☐ Yes (please describe)
    - ☐ No
36. Do you know what proportion of the population currently fish with bed nets?
    - ☐ Yes (please specify)
    - ☐ No
37. Do you think the alternative use of bed nets is having an impact on malaria?
    - ☐ Yes
    - ☐ No
    - ☐ Don't know

    Why do you think this?

38. If relevant, when distributing bed nets does your organisation have any procedures specifically to prevent the non-use or alternative use of bed nets?
    - ☐ Yes (please describe)
    - ☐ No
    - ☐ Don't know

Contact email address or telephone number (optional if you have witnessed fishing with bed nets or have an opinion on the matter and would like to discuss further

Thank you very much for your time. Please use the space below to add any other comments. If you have any photographic evidence of fishing with bed nets, other information to share (e.g. relevant reports) or would like to discuss this further, please email me at: rajina.gurung14@imperial.ac.uk.

If you feel you are able to give more information on bed net distributions or malaria control efforts in another fishing area in a developing country please select the 'yes, I have more information to give' box to fill out another survey for the separate location. If you would like to end the survey please select 'no, I do not have any more information to give on another location.'

- ☐ Further comments
- ☐ Yes, I have more information to give on another location
- ☐ No, I do not have any more information to give on another location

Appendix C. Chapter 5

Table C.1 - Fishing ground use at each site by gender for MNF deployment methods

Site	Fishing zone	Zone type	Chicocota catch events	Gender	Kutanda catch events	Gender
Malinde	Kibungo	Subtidal	1	M	0	-
	Liwala	Intertidal/shallow reef & seagrass	4	M	-	-
	Matumbawe	Subtidal	10	M	-	-
	Muicungo	Offshore island	-	-	2	F
	Muidumbe	Subtidal	1	M	-	-
	Muissani	Offshore island	5	M	-	-
	Nnelia	Intertidal	-	-	6	F
	Ntumumi	Intertidal	-	-	5	F
	Patacua	Intertidal	-	-	5	F
Lalane	Ilundo	Intertidal/shallow reef & seagrass	1	F	3	F
	Insimba	Intertidal	-	-	1	F
	Nauyeni	Intertidal/shallow reef & seagrass	-	-	1	F
	Nfinde	Intertidal	-	-	3	F
	Nhumbo	Intertidal	-	-	1	F
Nsangue ponta	Juma atique	Intertidal	1	M	-	-
	Liculamedi	Intertidal	1	F	1	F
	Lidamunda	Intertidal	-	-	8	F
	Likalamunda	Subtidal	-	-	1	F
	Muamba nsangue	Intertidal/shallow reef & seagrass	5	Both	8	Both
Quifuque	Metundo	Offshore island	-	-	3	F
Quirinde	Gonzaga	Intertidal	-	-	4	F
	Iyombe	Intertidal	-	-	1	F
	Mbuizy	Intertidal	-	-	2	F
	Namassiki	Intertidal	-	-	15	F
	Nanhane	Intertidal	-	-	3	F

Mosquito net fishing Focus group protocol

Focus groups are effective for capturing information about social norms and the variety of opinions or views within a population. The richness of focus group data emerges from the group dynamic and from the diversity of the group. Focus groups contribute to broad understandings by providing well-grounded data on social and cultural norms, the pervasiveness of these norms within the community, and people's opinions about their own values. The aim of these focus groups is to investigate the variability in mosquito net fishing (MNF) as a societal norm (or not) within several distinct communities, varying culturally and geographically.

Setting up the focus groups

Selection and sampling: Focus groups should be gender specific and comprise of fishers engaging in MNF relatively regularly (i.e. consider themselves MNF fishers). Fishers should be fully willing to participate and not subject to conflicts (e.g. spousal disapproval) – if any fishers express discomfort when approached or remain suspicious beyond explanation of the project objectives then they may not be suitable. The focus group will ideally be a mixture of social groupings i.e. not just village elders chiefs or fishing council leaders but a mixture of social roles. Use local contacts and leaders to recruit suitable people.

Exclusion criteria: The following groups of people should be excluded from participation in the study: those not participating in MNF, those under 18 years old, mentally ill, very frail and elderly, visitors (ie. non-residents of that village who cannot be considered migrant fishers). Questioning will relate to the prevalence of these groups participating in MNF, but they will not be questioned directly.

Numbers: 6-10 per group

Time: 1-2 hours (max.)

Location: A quiet and private location, preferably neutral (a public place) but private dwellings may be the only option – being sheltered from passers-by should be a priority. It should be out of the sun and with comfortable seating, a flat surface for exercises and protection from the elements. It is best to let the group choose a location where they feel comfortable but be aware to stipulate that these elements are key. Please make sure locally suitable refreshments are provided – it can be an incentive to provide these ~30 mins in to the FG to both provide a break and encourage people to stay until the end.

Roles of facilitators:

Focus groups should always be conducted by two members of staff:

Moderator

One researcher leads the discussion by asking participants to respond to open-ended questions (that is, questions that require an in depth response rather than a single phrase or simple "yes" or "no" answer) and/or take part in activities. It is important for the moderator to play an active role in keeping the discussion on track, avoiding or controlling arguments and encouraging all participants to contribute. Please see attached information on successful moderation if unsure of anything.

Note-taker

A second researcher (the note-taker) takes detailed notes on the discussion. Most of the more prescribed information will be captured on the exercise sheets, so the role of the note taker is to record the surrounding conversations that arise as part of the facilitated exercises. Depth of details is key here – nothing is useless information. Please see attached information on successful note-taking if unsure of anything.

Participant information

This information should be read in full to all focus groups participants prior to any questioning.

Intro to project: "You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to think about the following information carefully and discuss it with others if you wish.

We are carrying out a survey about mosquito net fishing in collaboration with the UK university Imperial College London. The survey is being carried out in several communities in four different countries. We are working to understand the role mosquito net fishing plays in fishing communities and how this has changed over time. The interviews ask specific questions about your life styles, the availability of food during the year, and your use of marine resources. The information you give may be used in future reports, articles or presentations by the research team, but your name will not be shared with anyone outside of the project. The information we get will help to create management plans for the activity in to the future.

This research is funded by the UK Natural Environment Research Council and supported by Imperial College London and the Zoological Society of London. Rebecca Short is the lead investigator and is a PhD student with these organisations."

Prior informed consent: **These focus groups and the information gleaned will remain entirely anonymous. At no point will people be required to give their names in order to take part. Despite this we must still ensure those taking part are of aware of what is required and formally consent to take part.**

"You have previously confirmed with our research team that you take part in mosquito net fishing and we would like to know more about this activity. Your participation is entirely voluntary, if you decide to take part we will mark your consent on a form we take away. The village chief also has a copy of this information but please ask if you would like any part of it read to you by the research team again. If you decide to participate in this research survey, you may withdraw at any time. If you decide not to participate in this study or if you withdraw from participating at any time, you will not be penalised and any data that we have collected will be deleted. If you want to withdraw from the study at any time, tell the person interviewing you and they will stop the interview and delete any information that you have given them.

We realise that mosquito net fishing is a sensitive topic within the community and can cause conflicts. We are independent researchers and do not work with or beside any government institutions. The information you give may be used in future reports, articles or presentations by the research team, but your name or any way of identifying you will not be shared with anyone outside of the project. No-one but the researchers will have access to the information. Anything that you tell us during this interview will remain confidential and your name will be removed from our database upon completion of our data collection. We will not ask you to tell us anything that could get you into trouble.

Do you have any questions?"

If all members verbally consent then both researchers should now sign the consent form. Please be fully satsfiesd that all participants fully understand their involvement. Please give out the provided business cards should anyone wish to contact the research team. Participants who do not want to remain for the duration of the discussion, for any reason, should be reminded of the confidentiality agreement, thanked for their participation.

Focus group instructions

Direct questions/probing

Objectives:

- To obtain information on aspects of MNF which do not easily fit within the activities planned.
- Questions will be split between the activities – to be asked at an appropriate time or the end of the exercise. Questions will be marked below with a † and associated question number.

Participatory mapping

Objectives:

- Map distinct habitat areas for nearshore and intertidal area
- Map fishing activity within these areas by demographic, gear type and mode of deployment of MNs (separate illustrations of modes of deployment)
- Map movement of various actors in MNF supply chain

Outline:

Draw a rough map of the coastline between the boundaries of the community's fishing zone (if this is clearly defined by local agreements – otherwise the 'effective fishing area' of a community). Make sure to include important geographical features and locally relevant land marks in order to orient yourselves (e.g. Leader's house, roads, mosque or church, boat mooring points). Make sure to leave a space for a legend – or alternatively do this on a separate piece of paper. A Google map can help to adjust scales and be accurate but shouldn't be used for the map itself as we want the features to be defined by the community (we aren't worried about mapping accuracy here – more that it is a way of gleaning details of fishing activities). The seaward extent of the map should be inclusive of important offshore features for *artisanal* fishing such as sand banks, islands, deep water channels etc. If the area is well known by the researchers then the basics of this map can be produced in advance, however we do not want any assumptions made as to fishing grounds wherever possible. Delineate the intertidal zone with a hashed line. In consultation with the group (adding to a legend as you go):

1. Add solid outlines of general distinct habitats in colour codes – coral reefs (yellow), seagrass beds (green), mangroves (brown), rocky shore, sand/mud flats (assumed to be anywhere intertidal not outlined). Add as appropriate.
2. Add gendered symbols to the habitat zones to show where men, women and children fish (harvest resources – gleaning is also relevant).
3. With the group identify the different gear types used and number them.
    a. It is important to question the group as to different deployment methods for MNs at this point and number them differently.

b. It would be great to also get diagrams or basic descriptions of these methods.
c. Add numbers to the habitat zones for each gear/method used there.

4. Add any commonly used landing sites *only for MNF catch* to the map with a T and ask participants to mark those where traders come to buy MNF catch with a $. If participants are able to identify where this catch is taken/sold please add this information to the notes.
5. Make sure to take several photos of the map in case of loss or damage. Do this for all exercises.

†[1]Extra information as to the fate of MN catch is very useful so probe as to the market chain – are large-scale traders buying it up? Does it go to other similar communities? Are there any external influences such as animal feed companies?

†[2]For methods where significant adaptations have been made to the MNs please probe as to the ownership and profit/catch division processes involved. How do people decide who they fish with? How do fishing groups form? Who owns the net/s? Are credit or reciprocal agreements involved?

Example map:

Seasonal calendar

Objectives:

- Identify occupational multiplicity of community and define income and food security activities
- Determine seasonality of trade-offs between various occupations over one year (status quo)
- Document determinants of variability in MNF throughout the year (weather, tides, cultural reasons, seasonal resources e.g. oysters)

Outline:

1. On a large piece of paper, get the group to free list all occupations undertaken by members of the community in a vertical list. MNF should obviously be one of these, but ensure that broad fishing types are separated (this is tricky to define as an instruction here and will be somewhat subjective – it is good to differentiate by broad gear types, vessels and intertidal or offshore activities but keep the number of diferent types achievable).
2. Get the group to define important seasonal changes over a single year in a corresponding horizontal list (creating columns) from the start of the year as defined by them – these may be defined by winds, rains, currents etc but should be locally meaningful (and preferably easy to associate with months! If months are familiar then please use these). Make notes as to the defining characteristics of these seasons. Be mindful of distinguishing unique events of past years and the desired generalisations about what 'normally' happens.
3. For each seasonal column, using 20 beans ask the group to divide the beans between the occupations as per their importance to general household incomes for that season.
4. Start from the beginning and now ask the group to divide the beans between the occupations as per their importance to general household food contributions in that season

(direct consumption). This will only be relevant to extractive activities, so ignore occupations such as casual labour and trade etc.

5. This is a time-bound snapshot activity and should represent the status quo – what is normal right now (so generalised over, say, the last 5 years – not supposed to be for collective memory).

†[3]Probe as to incomes from MNF when entering this on to the calendar → what is a good/average/bad daily income?

†[4]Probe as to household food contributions from from MNF when entering this on to the calendar → how many times a week do people consume MNF catch at home?

Timeline

Objectives:

- Determine start of MNF and key dates in fishery
- Determine perceptions of change over time in fishery → abundance and size
- Determine change in MNF activity over time
- Determine change in MNF catch over time
- Determine change in price of 'Medada' or equivalent over time

Outline:

1. Draw a timeline on a large piece of paper (time along horizontal axis) – with the group determine the oldest collective date of memory and mark as the starting point, the end point is the present day.
2. In consultation with the group mark several key, memorable events along the timeline in order to orient yourselves (e.g. national or local elections, start and end dates of conflicts, weather events, sporting events). This may be very tricky as many communities don't follow the calendar. However these events can be scaled ex-situ – the important thing is to get them in order and to have enough events along the timeline to effectively orient. You may have some events pre-prepared as prompts. The unit should be no finer than a year.
3. Make a point of marking the advent of MNF on the timeline. Make sure to pay attention to the surrounding debate – there are fishing methods that are very similar but didn't necessarily utilise MNs (e.g. cloth fishing) that can confuse. Try to mark all relevant dates but with the distinction of definitive introduction of MNs.
4. Using a pencil and in consultation with the community (giving adequate time for reflection and debate) draw a horizontal line representing perceptions of changes in <u>fish catch abundance</u> (total catch) over time (for the fishery in general, not just MNF). The vertical axis should represent this change, begin the line at the midpoint so as not to lead the respondents towards a decrease or increase (extend the line if necessary). Good prompts to encourage thought are to think about rate of change at each point and reflect this accordingly on the timeline. Once finalised solidify this line using a coloured pen (mark on legend).

5. Now repeat the process but asking respondents to think about the average number of people engaging with MNF over time. Use a different colour to solidify.
6. Finally, probe as to any differences in these engagement levels between male and female fishers. If the perception is that engagement differs significantly by gender then repeat for numbers of men and then women engaging with MNF over time. Use different colours to solidify.

†[5] Probe as to introduction of laws and/or local regulations relevant to fishing and especially MNF. Pay attention to any mention of conflicts e.g. illegal activity by migrant fishers.

†[6] When did MNs start being given out for free? When did they last receive some nets? What does this mean for the number of people sleeping under one? Do people ever buy MNs?

†[7] Did you receive any information with the distribution of nets? Did anyone talk to you about the nets?

Future visioning matrix

Objectives:

- To identify perceptions of positive and negative aspects of MNF to men, women, the community and the environment.
- To glean local perceptions of MNF's role in the future
- To informally document visions of the future and how MNF fits in to that
- To identify opportunities for intervention

Outline:

1. On a large piece of paper draw out the matrix below.
    a. Rows are positive and negative aspects
    b. Columns relate to: individuals (you); the community (you all); the environment (nature); the future (your children's future i.e. long term)
2. One column at a time, facilitate discussion with the group as to the positive and negative aspects of MNF, starting with individuals and finishing with implications for the future.
3. Prompts to facilitate discussion about the future include discussion about whether or not people would like their children to MNF, what opportunities MNF provides and the perceptions of MNF to provide in to the future.

	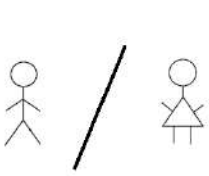	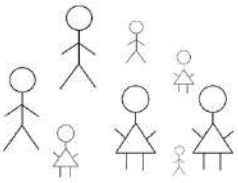	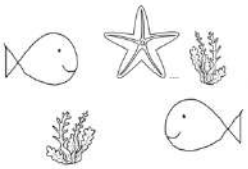	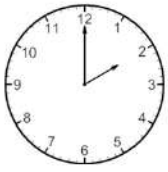
				
				

Figure 2 - Participatory resource and gear use maps for OSOL sites

Figure C.4 – Additional information for species of interest to discussions surrounding Kutanda and Chicocota fishing. Values taken from FishBase (Froese & Pauly, 2018)

	Species	Common name	Trophic level	Feeding group	Commercial use	Habitats	Resilience	Vulnerability
Chicocota interest	*Siganus sutor*	Shoemaker spinefoot	2	Herbivore	commercial; aquarium	Reef-associated, inshore	High	Low
	Leptoscarus vaigiensis	Marbled parrotfish	2	Herbivore	Commercial; aquarium	Seagrass or hard substrate	high	low to moderate
	Lethrinus lentjan	Pink ear emperor	3.9	Carnivore	Highly commercial	Sandy coastal, juveniles in seagrass and mangroves	Medium	low
	Plectorhincus gaterinus	Blackspotted rubberlip	4	Carnivore	Commercial; gamefish	Coastal reefs and sandbanks	Medium	moderate
	Pomadasys furcatus	Banded grunter	3.5	Carnivore	Commercial	Reef-assocated	Medium	Moderate to high
	Lethrinus variegatus	Slender emperor	3.8	Carnivore	Minor commercial	Sandy, weedy areas, juveniles abundant in shallows	Medium	Low to moderate
	Apogon *sp.*	Cardinalfishes	*3.5	Carnivore	Aquarium	Reef-associated (noctural)	*High	*Low
	Parapeneus macronemus	Long-barbel goatfish	3.5	Carnivore	Commercial; aquarium	Reefs, sandy & weedy bottoms	Medium	Low to moderate

	Neoglyphidodon carlsoni	Carlson's damsel	2.8	Omnivorous	NA	Fringing reefs	High	Low
	Papiloculiceps longiceps	Tentacled flathead	4	Carnivore	Subsistence	Near reefs	Medium	Moderate to high
	Scarus ghobban	Blue-barred parrotfish	2	Herbivore	Commercial; aquarium	Reef-associated	Medium	Moderate
Both	*Gerres oyena*	Common silver biddy	2.7	Carnivore	Fish meal	Lagoons, estauries, sand flats	High	Low
	Lethrinus variegatus	Slender emperor	3.8	Carnivore	Commercial minor	Inshore nearr reefs	Medium	Low-moderate
	Plotosus lineatus	Striped eel catfish	3.6	Carnivore	Commercial, aquarium	Reef-associated, coastal benthic	Medium	Low-moderate
Kutanda interest	*Sillago sihama*	Silver sillago	3.3	Carnivore	Commercial, aquaculture	Sand flats, mangroves, estuaries	High	Low
	Clupediae *e.g. Spratteloides delicatulus*	Sprats, sardines, herrings	3.1	Planktivore	Commercial; bait	Inshore pelagic	High	Low
	Hyporhamphus affinis	Tropical halfbeak	3.5	Omnivore	NA	Reef associated	High	Low-moderate

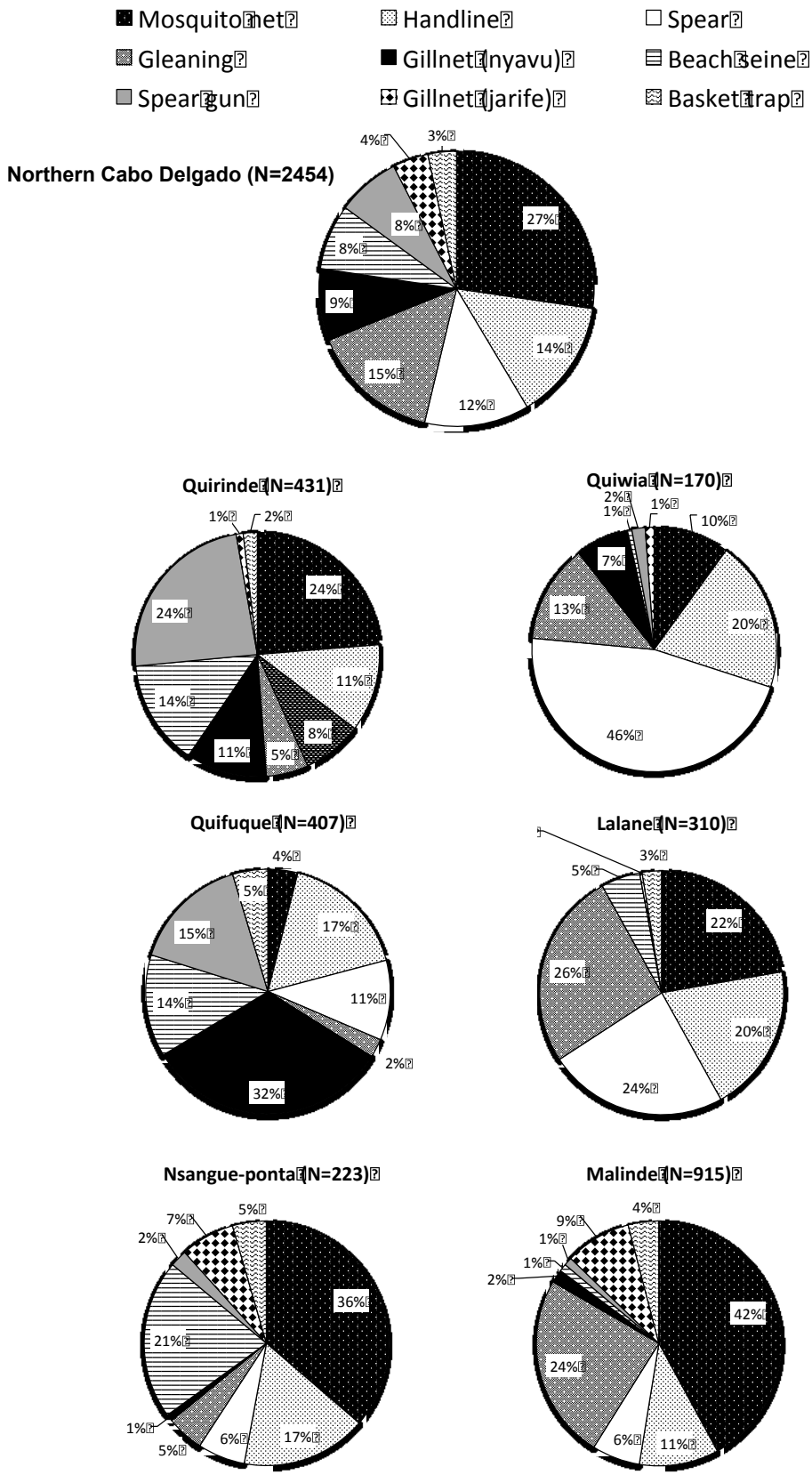

Figure C.5 - Proportional gear use by fishers in OSOL sites, taken from Samoilys et al., 2018 (In press)

Appendix D. Chapter 6

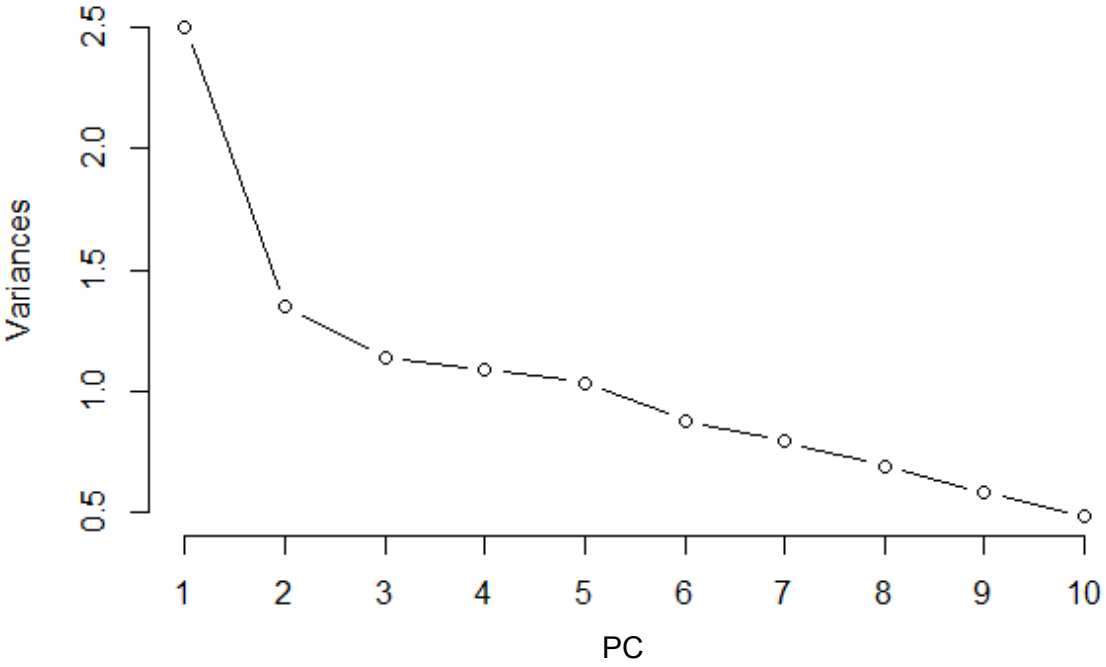

Figure D.1 - Scree plot for Principal Components Analysis of Material Style of Life indicators

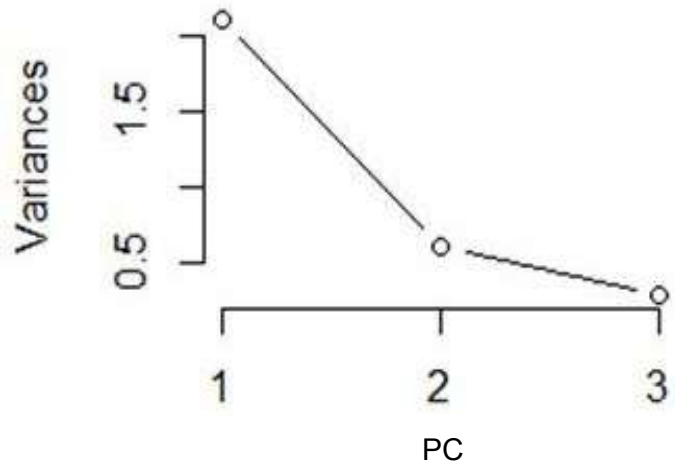

Figure D.2 - Scree plot for Principal Components Analysis of Economic Mobility indicators

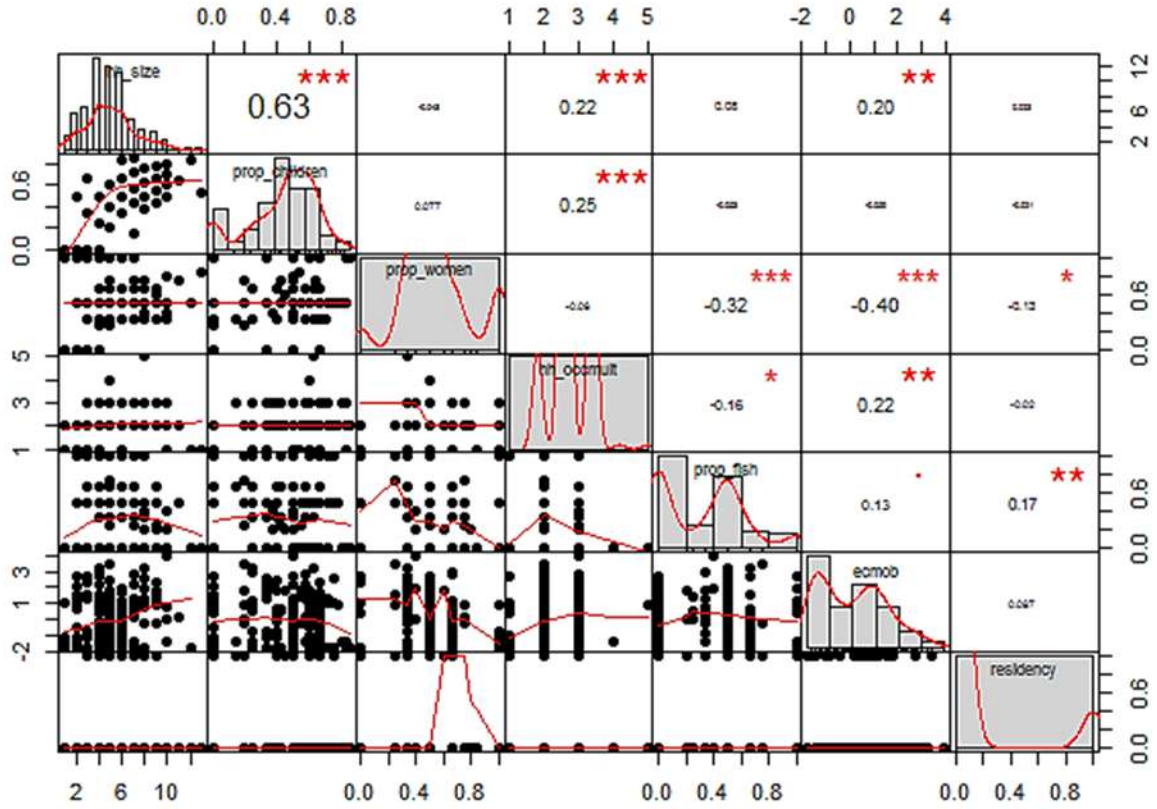

Figure D.3 - Correlation plots with correlation coefficients and histograms for household characteristics variables

Table D.4 - Variance inflation factors for household characteristics variables

Variables	VIF
hh_size	2.022568
prop_children	1.978557
prop_women	1.368042
hh_occmult	1.182326
prop_fish	1.218085
ecmob	1.321088

Table D.5 - Descriptive statistics for the household characterisation variables. Economic mobility values are attributed by PCA scores

Continuous/discrete variables	**Mean (SE)**	
	nMNF (0) **n = 116**	**MNF (1)** **n = 127**
Intercept	-	-
Household size	4.929 (0.21)	5.118 (0.19)
Occupational multiplicity	2.027 (0.06)	2.236 (0.05)
Proportion hh primarily fisher	0.318 (0.03)	0.320 (0.03)
Proportion of hh <16yrs	0.432 (0.02)	0.484 (0.02)
Proportion of hh female	0.466 (0.02)	0.584 (0.02)
Economic mobility (PCA1)	-0.068 (0.16)	0.052 (0.14)
Categorical variables (0/1)	**Proportion of households (y)**	
Fish new last 5 yrs (y=1)	0.150	0.134
Leadership position (y =1)	0.062	0.134
Household head female (y=1)	0.106	0.197
Household are itinerant (y=1)	0.133	0.031

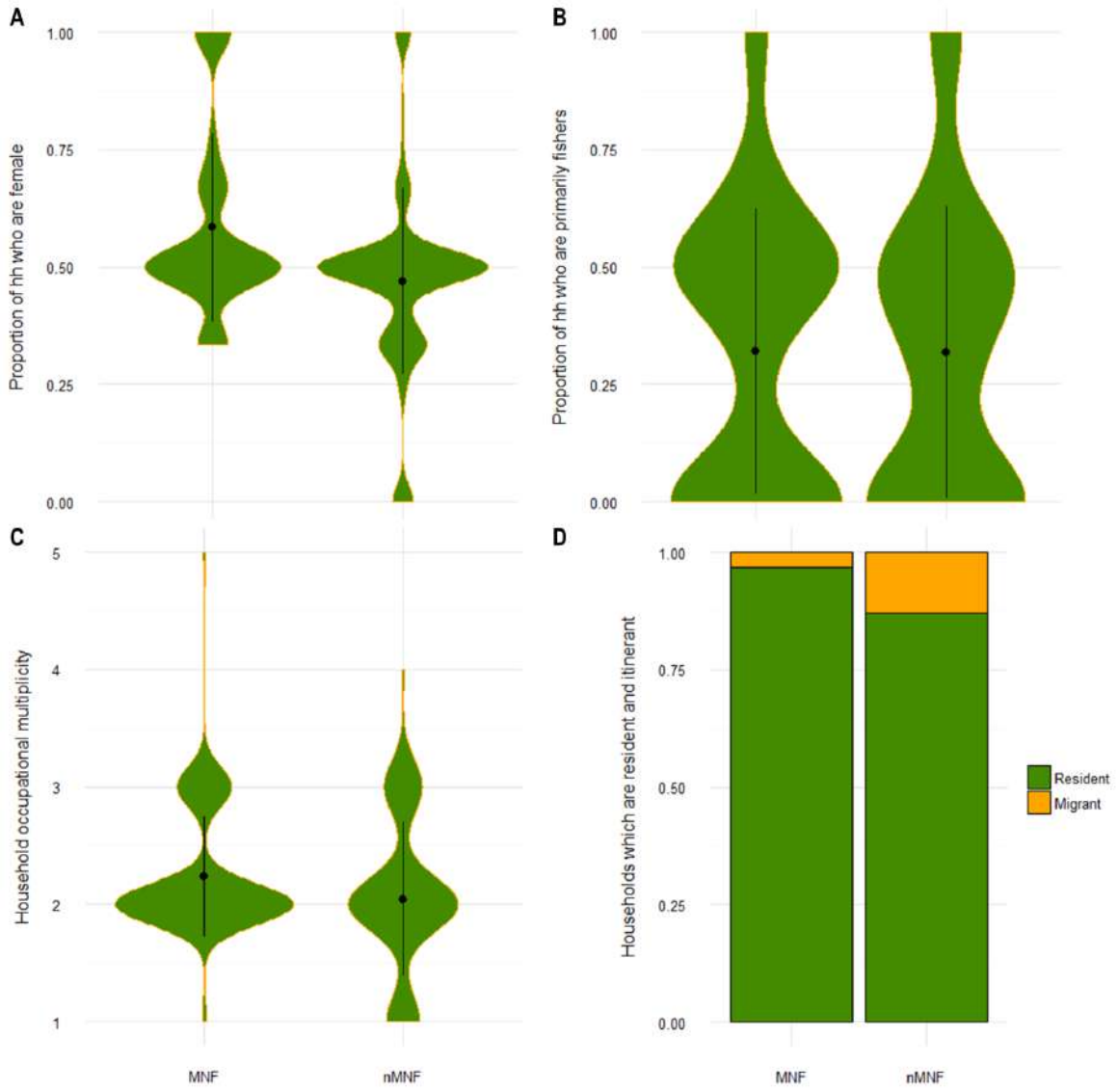

Figure D.6 – Violin and bar plots showing data distributions for all significant variables from MNF characterisation model with means (black dot) and standard deviation (black line) values for MNF (n = 127) and nMNF (n=116) households: A = Proportion of household adults who are female, B = proportion of adults in household who consider fishing to be their primary occupation, C = household occupational multiplicity, D = proportion of total households who are permanent (resident) or itinerant (migrant).

Figure D.7 - Summary statistics for household wealth indicators for MNF and nMNF households. Material style of life values are attributed by PCA scores (Table 12).

Continuous/discrete variables	Mean (SE)	
	nMNF (0)	**MNF (1)**
Material style of life	0.128 (0.15)	-0.114 (0.14)
Income change (previous 5 years) -10 to +10	-1.218 (0.44)	-2.121 (0.37)
Categorical variable (0/1)	**Proportion of households (y)**	
Household member in VSLA (y =1)	0.218	0.22

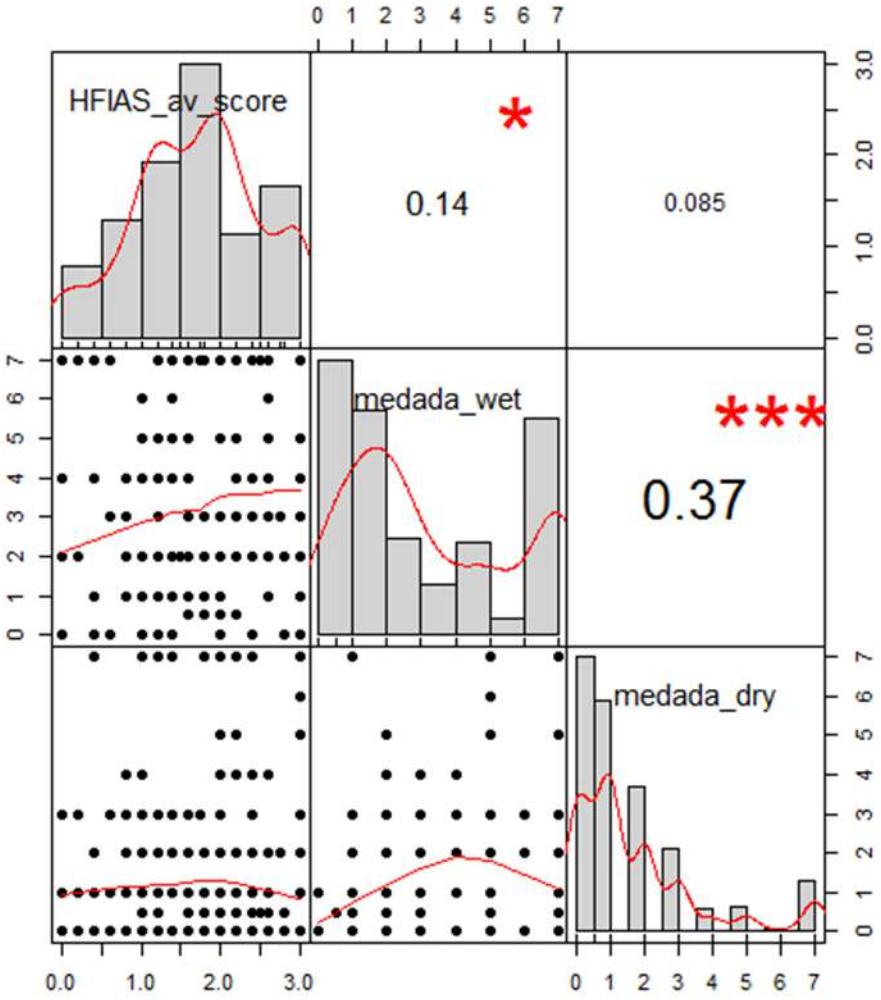

Figure D.8 - Correlation plots with correlation coefficients and histograms for food security variables

Figure D.9 - Variance inflation factors for food security variables

Variables	VIF
HFIAS_av_score	1.020007
medada_wet	1.173731
medada_dry	1.160841

Figure D.60 - Summary statistics for household food security indicators for MNF and nMNF households.

Continuous/discrete variables	Mean (SE)	
	nMNF (0)	**MNF (1)**
Intercept	-	-
HFIAS score	1.69 (0.09)	1.74 (0.07)
Medada consump. (rainy)	2.833 (0.24)	3.93 (0.23)
Medada consump. (dry)	1.52 (0.19)	1.85 (0.18)
Categorical variable (0/1)	**Proportion of households (y)**	
Saved food (y=1)	0.44	0.5

Appendix D.11 – Cabo Delgado mosquito net fishing household survey (English)

Mosquito net fishing household survey

Caros Participantes:

We are carrying out a survey about mosquito net fishing for the project "Nosso Mar, Nossa Vida" in collaboration with the UK university Imperial College London. The project is for six communities in Palma District. The project partners (AMA; Bioclimate; ZSL; CORDIO; University Unilurio; Universidad Nova) want to improve how the community are involved with fisheries co-management to hopefully improve food security for the people here.

We are doing this survey to understand how mosquito net fishing contributes to food and incomes for the community and how important it is for the fishery and the environment now. Overall we want to understand the role mosquito net fishing plays in the community. The interviews ask specific questions about your lifestyles, the availability of food during the year, and your use of marine resources. The information you give may be used in future reports, articles or presentations by the research team, but your name will never be given or shared with anyone outside of the project.

The interview will take approximately X hour of your time. Your name will not be recorded and everything that you say will be kept completely safe. We are independent researchers and do not work with or beside any government institutions. No-one but the researchers will have access to the information. We are interested in what you think because you live in this area and have experiences of yourself or others using this type of fishing gear. If you decide not to take part that is also okay. Participation is totally voluntary and you can withdraw at any time. Should you choose to withdraw, any data which may have previously been collected will be deleted. Please feel free to ask questions of the team at any point. If you wish to contact us later please do so at MOCIMBOA OFFICE.

☐ PIC form signed by primary researcher

Date:_____ Primary researcher:_____ Site:_____ Census code:_____

Name (household head):_____ HH code:_____

1. a. Permanent residents always here ☐ b. Permanent but did live elsewhere ☐ → Year arrived: _____

c. Migrate yearly/regularly ☐ → Months here: J F M A M J J A S O N D

2. Household demographics

	a. Sex	b. Age	c. Estado civil	d. Relação a chefe	e. Escolaridade	f. Literate Y/N	g. Main occ.	h. Languages
Chefe de fam.								K M S P I O
Adult 2								K M S P I O
Adult 3								K M S P I O
Adult 4								K M S P I O
Adult 5								K M S P I O
Adult 6								K M S P I O

K = Kimwani; M = Macua; Ma = Makwe; S = Swahili; P = Portuguese; I = Inglês; O = Outros _____

2i. No. of children (<16yrs) in HH: _____ 2j. Any CCP members or positions of responsibility? _____

3. Occupations – engaged in over the last year

Occupations	a. No. of ppl engaging		b. New activity?	c. Income score (/20)	d. Consumption score (/20)	e. Time score (/20)
	M	F	Last 5 yrs?			
Fishing/gleaning						
Farming						
Mariculture						
Trader (fish/crops)						
Salaried employment						
Shop owner						
Tea shop owner						
Sm. business owner						
Tourism						
Other:_____						

4. Fishing – household engagement over the last year (just for time spent fishing)

Gear	a. No. of ppl engaging		b. Own/ Share	c. New activity?	d. Fishing income score (/20)	e. Fishing consumption score (/20)	f. Fishing time score (/20)
	M	F		5 yrs?			
Gleaning							
Harpoon/spear							
Speargun							
Mosquito net							
Gill net							
Circle net							
Jarifa							
Beach seine							
Handline							
Basket trap							
Other:____							

How many people in hh receiving pension? _____

5. Catch importance (ranked)

	a. Catch?	b. Rank income	c. Rank consumption
Crabs	☐		
Lobster	☐		
Shrimp	☐		
Polvo	☐		
Oystes and shells (e.g. macome)	☐		
Lula	☐		
Sea cucumber	☐		
Medada	☐		
Reef fish	☐		
Deepwater fish	☐		
Outros	☐		

6. Income/assets/savings

a. What is an average daily income (mzn) for your household today and 5 years ago?

	Now (2016)	Then (2011)?
Average daily income		

b. How many adults are VSLA members? Male: _____ Female:_____

c. How much does your household have in VSLA savings?

d. Do you have any other monetary savings? How much in the last year?

e. Do you have any other types of savings?

f. Access to loans/loans taken

	Access?	Taken in last yr?	Purpose?
VSLA			
Family/friends			
Bank			
Government scheme			
Independent			
Other_____			

*Please give details of any 'others' on a separate sheet

g. Material style of life (MSL):

House (note other):

Floor material

Ground/mud	Bamboo	Wooden boards	Cement	Mosaic

Wall material

Daub + wattle	Improved D+W	Wood	Metal	Brick	Cement

Roof material

Straw	Metal	Lusolite

Own house ☐ Rent house ☐ Any other houses? No._____

Transport (count):

Bicycle	Motorbike	Car	Other _____
Canoe	Lancha/Dhow	Outboard motor	Other _____

Material Goods (how many? must be functioning!):

No. of mobile phones:_____ No. of goats: _____ No. of chickens:_____ No. of coconut trees:_____

Gas stove	Water tank	Solar panel	Car battery	Generator
Electric fan	Radio	TV	DVD/Video	Satellite dish

Fridge/freezer	Piped water	Mains electricity	Chairs	Electric light

7. Food diversity

a) Ranking (consumption frequency)

Household dietary diversity	Regularly consume (>once pw)		Usually buy?
	SEM	NEM	
Cereals (rice, xima, bread, millet, maize)	☐	☐	☐
Roots and tubers (cassava, batatas)	☐	☐	☐
Vegetables (cabbage, cebola, pepino)	☐	☐	☐
Fruits (mango, banana)	☐	☐	☐
Meat/poultry (galinha, goat)	☐	☐	☐
Ovos	☐	☐	☐
Fish and seafood	☐	☐	☐
Pulses/legumes/nuts (cashews, beans)	☐	☐	☐
Oil/fats (butter, oil)	☐	☐	☐
Sugar (cane, honey, sweets)	☐	☐	☐
Misc. (tea, coffee, condiments)	☐	☐	☐

b) How many times per week do your family consume medada (if at all)? SEM:_____ NEM:_____

8. Food security (HFIAS):

In the past 12 months (think of one wet and one dry season) were there times when:	**Never**	**Rarely**	**Sometimes**	**Often**	**Don't know**	**Refuse**
a. You or others in your household worried about not having enough food to eat because of a lack of money or other resources?						
b. Still thinking about the last 12 MONTHS, were there times when you or others in your household were unable to eat healthy and nutritious food because of a lack of money or other resources?						
c. Were there times when you or others in your household had to skip a meal because there was not enough money or other resources to get food?						
d. Were there times when your household ran out of food because of a lack of money or other resources?						
e. Were there times when you or others in your household went without eating for a whole day because of a lack of money or other resources?						

9. Mosquito net access and use

a. How many nets does your hh have? _____

b. How many people sleep under a net most nights: Children _____ Adults_____

c. How did you access these nets (can be more than one)

Bought (trader) _____mzn	Bought (town) _____mzn	Free distribution	Gift	Other _____

d. *If free when was the last distribution here?

e. *Were you given any information or education, or were you visited by a health worker when you received this net?

f. What do you do with nets that are no longer useful on your bed?

10. Mosquito net fishing specifics

Methods (do not lead – let them explain and tick off appropriately)

Method	**a. No. fishers**		**b. Target species**	**c. Ranked importance**	
	M	**F**		**Income**	**Food**
Shallow seine (3/4 ppl)					
Seine person alone					
Scoop net w/frame (polvo)					
Boat seine/trawl					
Xicocota/ Mukuelele					
Other					

11. Perceptions (discussed as a household)

a) Use matrix on back and fill in during discussion (encourage 3 answers for each – probe for direct conflict issues as possibly not obvious) – how is MNF good and bad for i) you and your family, ii) the community iii) the environment:

b) Would you like MNF to continue in to the future?

c) Would you like your children to MNF?

d) What would you rather you/they were doing?

e) Are you aware of any regulations/rules for MNF?

f) Do you think these rules are appropriate?

12. Scenarios

I am now going to discuss with you some possible past and future scenarios in order to understand what has changed or might change with your fishing practices based on the state of your catch. The future scenarios are fictional and are not based on predictions.

a. I would like you to think generally about your overall catch over the last five years. Thinking about the number of fish now, has there ever been a time where your catch reduced by so much that you changed something about the way you fish?

What did you do?

Fish less	Keep fishing at same amount	Fish harder (more frequent/ fish longer)	Fish elsewhere (outside of current fishing grounds/village)	Change gear/target	Leave fishery (for what?)	Leave village (where?)

Other

_____

b. I would like you to think specifically about your MN catch over the last five years. Thinking about the number of fish now, has as there ever been a time where your catch reduced by so much that you changed something about the way you fish?

What did you do?

Fish less	Keep fishing at same amount	Fish harder (more frequent/ fish longer)	Fish elsewhere (outside of current fishing grounds/village)	Change gear/target	Leave fishery (for what?)	Leave village (where?)

Other

_____

b. With that in mind, but now thinking about the current number of fish and what might happen in the future:

If you were to consistently get 20% lower overall catch what would you do? (use beans)

Fish less	Keep fishing at same amount	Fish harder (more frequent/ fish longer)	Fish elsewhere (outside of current fishing grounds/village)	Change gear/target	Leave fishery (for what?)

Other

_____

d. If you were to consistently get 50% lower overall catch what would you do? (use beans)

Fish less	Keep fishing at same amount	Fish harder (more frequent/ fish longer)	Fish elsewhere (outside of current fishing grounds/village)	Change gear/target	Leave fishery (for what?)

Other

_____

e.** *If you were to consistently get 20% lower MNF catch what would you do? (use beans)*

Fish less	Keep fishing at same amount	Fish harder (more frequent/ fish longer)	Fish elsewhere (outside of current fishing grounds/village)	Change gear/target	Leave fishery (for what?)

Other

_____

f.** *If you were to consistently get 50% lower MNF catch what would you do? (use beans)*

Fish less	Keep fishing at same amount	Fish harder (more frequent/ fish longer)	Fish elsewhere (outside of current fishing grounds/village)	Change gear/target	Leave fishery (for what?)

Other

_____

---------- **MUITO OBRIGADO!!** ----------