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Abstract

Marine Protected Areas (MPAs) have the potential to support small-scale fishers in managing their resources. However, a general failure to consider the varying levels of vulnerability of fishers has resulted in MPAs that, often unintentionally, adversely impact small-scale fishers. Furthermore, when fishers lack the capacity to adapt to MPA-related changes, MPAs may fail to meet conservation objectives because fishers do not comply with MPA regulations. In this study, we developed a systematic method to identify individuals who are most vulnerable to being negatively impacted by no-take MPAs through an index that represents individual-level vulnerability. We designed a method for identifying these individuals based on four socioeconomic factors pertaining to vulnerability to MPA restrictions: livelihood diversity, education, age and wealth, then applied this method in two socially and economically heterogeneous communities in Myanmar's Myeik Archipelago. We used empirical data collected from 80 small-scale fishers in this area to represent each factor, then generated a local-level 'livelihood impact potential index' (LIPI) that reflects the degree to which a no-take MPA would impact an individual fisher's ability to support his or her livelihood. When attributed to each fisher's most frequented fishing ground, the LIPI can identify locations where no-take MPAs would be most detrimental to small-scale fishers' livelihoods based on their level of vulnerability. The LIPI can thus be used alongside ecological and commercial fishing data to support planners in designing local-scale MPAs that maximise positive impact on biodiversity and minimise adverse impacts on the most vulnerable fishers in a community.

Keywords	Marine Protected Areas; Small-scale fisheries; Livelihoods; Conservation planning; Myanmar; Vulnerability;

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1. Introduction

Ninety-seven percent of small-scale fishers live in least developed countries (WB 2012). The value of marine resources to these fishers lies not only in employment and nutrition (Kawarazuka and Béné 2010, Kawarazuka and Béné 2011, Barnes-Mauthe et al. 2013), but also in cultural, social and bequest values, that operate synergistically in their contribution to fishers' wellbeing and livelihoods (Béné 2006, Salas et al. 2007, O'Garra 2009).

Since fish biomass caught from the world's oceans peaked in the late 1980s, global fish production has declined at an unprecedented rate (Pauly et al. 1998). Overexploitation of marine resources has resulted in adverse ecological consequences (e.g. Pauly et al. 1998, Cinner and McClanahan 2006, Januchowski-Hartley et al. 2015), and subsequent negative impacts on the livelihoods of many marine fishers (Clausen and York 2008). Negative impacts are amplified for small-scale fishers in developing countries who often operate in open-access and low-productivity fisheries, and are in perpetual competition with commercial fishing fleets for a shared marine resource (Andrew et al. 2007).

Galvanised by increasing pressure on marine fisheries and competition between resource users, international attention has focused on mechanisms to protect marine ecosystems while simultaneously seeking opportunities to support the sustainable use of marine resources. Marine protected areas (MPAs) have been endorsed as one means to achieve the dual objectives of biodiversity conservation and fisheries management (Roberts et al. 2001, Garcia et al. 2014). Over time, no-take MPAs can increase fish biomass, and "spillover" into adjacent open-access waters (NRC 2001, Topor et al. 2019). MPA zoning can also enhance food security for specific fishing subgroups by reallocating fishing rights which thereby reduces local competition for fishing resource, such as the restriction of trawl vessels to allow only for artisanal fishers in certain zones (Christie et al. 1994, Himes 2003, Mascia et al. 2010).

While MPAs have the potential to benefit small-scale fishers, considerations concerning how capable local resource users are to adapt to MPA-related restrictions, and hence how vulnerable they are to negative consequences, are often overlooked (Mizrahi et al. 2018, Mizrahi 2019). Vulnerability can be defined as the state of susceptibility to harm from perturbations (Adger 2006). A person's vulnerability is influenced in part by his or her ability to adapt to losses or alternations in resource access, and hence their potential to suffer negative consequences related to a change such as the establishment of an MPA (Adger and Vincent 2005, Gallopín 2006). While some individual fishers might be in a position to adapt to livelihood restrictions, others are more vulnerable to MPA-related restrictions due to socioeconomic limitations related to wealth, livelihood diversity, education and age (Cinner et al. 2009, Cinner and Bodin 2010, Launio et al. 2010, Setiawan et al. 2012, Gurney et al. 2015, Voyer et al. 2015 in Mizrahi et al. 2018). Fishers who are most wealthy are generally best placed to benefit from local government arrangements (Adger and Kelly 1999), and will often position themselves well in decision-making

situations (Christie 2004). These fishers also experience fewer risks associated with attempting a new livelihood activity which serves as a safeguard if access to fisheries resources is restricted (MacNeil and Cinner 2013). In contrast, less wealthy fishers with fewer livelihood strategies and low education levels are generally most likely to be negatively impacted by restriction on fisheries resources, and are less likely to have the skills to attempt new livelihood opportunities (Cinner et al. 2012). Furthermore, as age increases, opportunities to diversify livelihoods decrease (Cinner et al. 2012), as does openness to gaining new environmental knowledge (Gurney et al. 2015).

Perversely, poorly designed MPAs often end up negatively impacting the most vulnerable people, who are most immediately affected by new regulations. Restricting the resource use of the most vulnerable can manifest in poverty traps, a reinforcing mechanism whereby people find it challenging to escape poverty unless a significant amount of economic capital is made available (Azariadis and Stach 2005). This is particularly true in least developed and low-income countries in which many of the world's small-scale fishers operate, and where fisheries provide one of the few opportunities for protein and income. For cases where small-scale fishers are not well placed to adjust to MPA-related changes, adverse impacts on vulnerable fishers can also result in adverse consequences for biodiversity, with fishers failing to comply with MPA regulations unless strong enforcement is present (Ostrom 2007). Potential biodiversity gains from MPAs are therefore less likely in cases where policymakers fail to consider the local needs and context of small-scale fishers. For example, responding to threats of overexploitation and decline in fisheries, Thailand's government has implemented 16 National Marine Parks (NMPs) within its Andaman Sea territorial boundaries (Bennett and Dearden 2014). While these NMPs were intended to support conservation, the parks are also situated in areas close to many of the 621 small-scale fishing communities that inhabit the Andaman coastline (Panjarat 2008). Local fishers were prohibited from harvesting in their usual fishing grounds, and one study of small-scale fishers in areas adjacent to the NMPs found that they felt they could not support themselves if they were excluded from fishing in those areas (Bennett and Dearden 2014). While Thailand's NMPs might contribute to national-level protected area targets (CBD 2010), local perceptions of these NMPs are mostly negative in small-scale fishing and subsistence harvesting communities, where fishing activities are generally seen to be adversely impacted by NMPs. These perceptions have resulted in protected areas with low compliance and hence limited biodiversity benefits (Prasertcharoensuk et al. 2010, Bennett and Dearden 2014).

In most studies that consider the livelihood needs of fishers in MPA planning, socioeconomic factors are included in the form of reducing livelihood costs of conservation to stakeholder groups as one homogenous entity, such as commercial fishers (Richardson et al. 2006), or entire communities (Thiault et al. 2018). When applied at a local scale, these methods become problematic because they assume there is no variation between costs to different individuals within each stakeholder group, and can lead

to MPAs that have inequitable impacts on individuals. Inequitable distribution of costs and benefits within a community can manifest as 'elite capture' whereby elites use their positions of status and power to promote their own interests at the expense of others (Béné et al. 2009). Due to the social and economic heterogeneity of many small-scale fishing communities, the impacts of MPAs are likely to vary among fishers depending on individual levels of vulnerability. Furthermore, fishers from the same community visit a range of fishing grounds influenced by factors including equipment available (e.g. access to a motorised vessels), time available, level of experience, and traditional values (unpublished data). This introduces further spatial complexity into whom within a community will be most affected by an MPA, and has, to the best of our knowledge, not been addressed in previous studies.

In this study, we aimed to develop a systematic method to identify the optimal location for no-take MPAs so that they limit negative impacts on small-scale fishers with the highest levels of vulnerability to experiencing negative consequences from MPAs (heron referred to as 'vulnerability') within a community. We designed a method for identifying these individuals based on four socioeconomic factors related to vulnerability, a key characteristic that mediates people's vulnerability to change (adapted from Mizrahi et al. 2018), and applied this method in two socially and economically diverse communities in Myanmar's Myeik Archipelago. We used data collected from small-scale fishers in this area to represent each factor, then generated a local-level 'livelihood impact potential' index that reflects the degree to which a no-take MPA would impact an individual fisher's ability to support his or her livelihood. When this score is attributed to each fisher's most frequented fishing ground, the index can help identify locations where MPAs would be most detrimental to small-scale fishers' livelihoods based on their level of vulnerability.

2. Material and methods

2.1 Socioeconomic Factors

A systematic review conducted in Mizrahi et al. (2018) identified 17 socioeconomic factors influencing the nature and level of impacts that MPAs have on livelihoods. In that study and the present one, impact is defined as the outcome resulting from protection compared to a counterfactual scenario of no protection (Pressey et al. 2015). From the initial list of 17 factors, we identified four local-level factors relevant to an individual's vulnerability to MPA restrictions: *livelihood diversity, education, age*, and *wealth* (Table 1). In combination, these measures indicate the degree to which individual small-scale fishers' livelihoods would be impacted by a no-take MPA. We used empirical data obtained from surveys with 80 fishers in the Myeik Archipelago to represent these factors (Table 1).

Table 1. Socioeconomic factors (adapted from Mizrahi et al. 2018) that influence how small-scale fishers' livelihoods can be impacted by the establishment of MPAs. Refer to Mizrahi et al. 2018 for references to the original literature supporting how each socioeconomic factor can influence positive livelihood outcomes.

Socioeconomic Factor	Relationship with adaptive capacity	Survey Data
Livelihood diversity	Individuals with the fewest livelihood strategies are generally most likely to be negatively impacted by restriction of resources and are less likely to support MPAs if MPAs are perceived to reduce their access to food or income.	Total number of different occupations per individual
Education level	Formally schooled fishers are more likely to be aware of, understand and support conservation efforts such as MPAs, and have more skills to take on new livelihood opportunities.	Number of formal schooling years completed per individual
Age	Younger individuals have greater potential to gain environmental knowledge and have increased openness and opportunities to embrace change. Older individuals will more likely be negatively impacted by MPAs due to more risk associated with attempting a new livelihood strategy.	Age of the individual
Wealth	Individuals with lower wealth (represented here as household Material Style of Life) face greater challenges in adapting to restrictive legislation.	Factor score of household items of the individual representing Material Style of Life Index (Pollnac and Crawford 2000)

2.2 Ethics

This study was carried out under human ethics permit xxx. All participants provided oral consent to be interviewed. Prior to being interviewed, all respondents were informed of the purpose of the interview, the confidentiality of information provided, and the right to omit questions or end the interview at any stage.

2.3.1 Study site

This study draws on data from three fisheries-dependent communities located in the Myeik Archipelago in Southern Myanmar: Don Pale, Lin Long and Makyone Gallet (Figure 1). Myanmar's small-scale fishers operate in a general context of poverty, low education, ethnic diversity and strong dependence on fisheries (Schneider and Thiha 2014). Marine resources are a major contributor to food security, providing direct livelihoods for an estimated 1.4 million fishers (DoF 2017), with per capita consumptions remaining one of the highest in the world (FAO 2012). Fishing is the main source of livelihood for those living in the Myeik Archipelago, and can be characterised as a multi-gear, multi-species fishery with limited access to outside markets (Schneider and Thiha 2014). Furthermore, these fishers are from diverse ethnic backgrounds with varying historical association with the islands (Schneider and Thiha 2014). These diverse community characteristics represent a relevant case study to examine how the restriction of resource extraction would impact different individuals and inform how MPAs can be designed to minimise detrimental livelihood impacts on the most vulnerable community members.

In the Myeik Archipelago, MPAs are mostly in the inception stage of design and development. For example, in the south of the Myeik Archipelago, Lampi Marine National Park (MNP) is an IUCN category II MPA that theoretically functions through a top-down governance system in which the state controls management through laws and other regulations, with the dual objective of protection of biodiversity and sustainable human development (MOECAF 2014). While the park boundaries have been allocated and a draft zoning plan has been designed, management inputs are still in the early stages, resulting in minimal biodiversity or livelihood implications from the MNP to date (Dearden 2016).

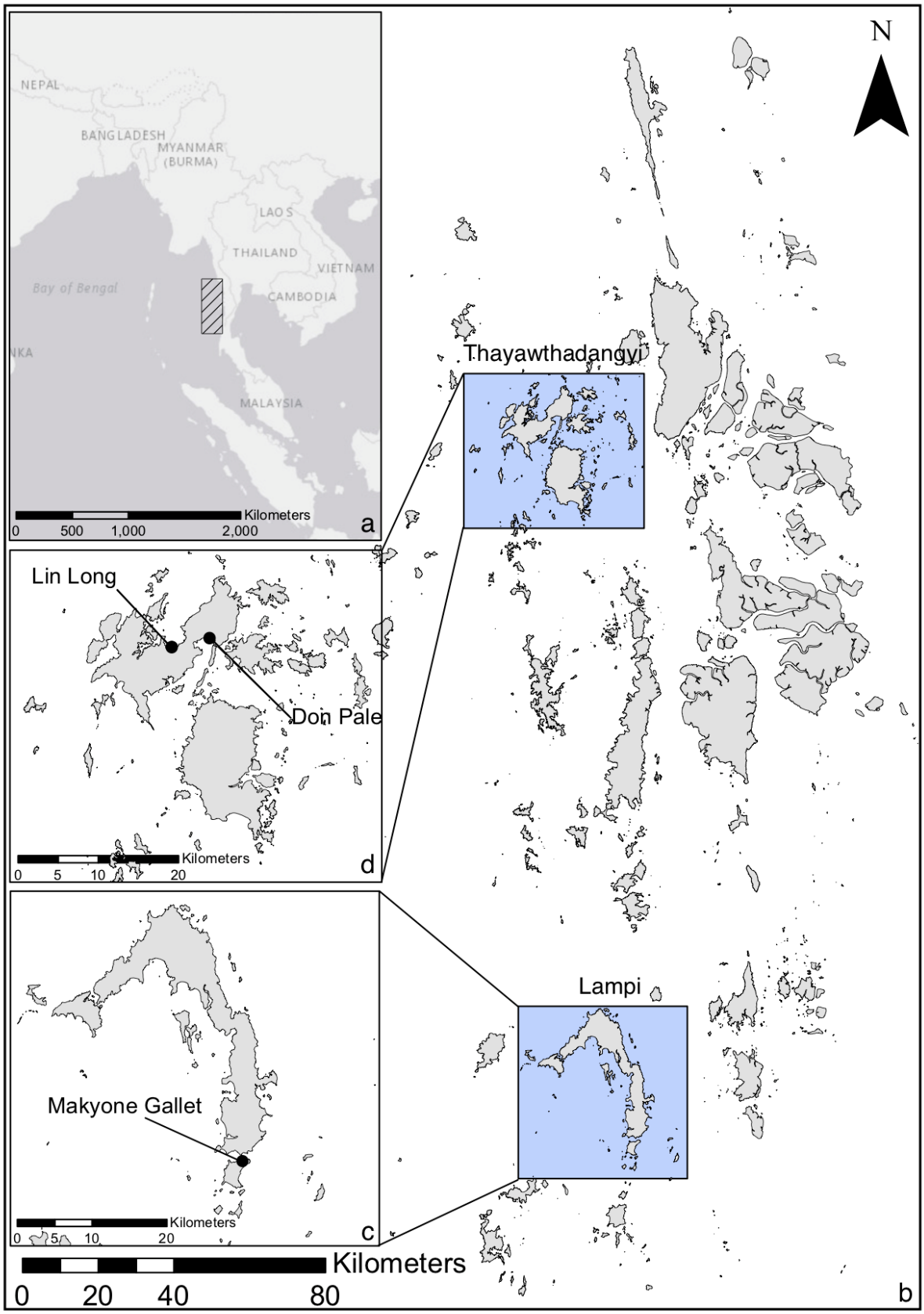

Figure 1. Map of the Myeik Archipelago highlighting three study sites in Don Pale, Lin Long and Makyone Gallet. a: Myanmar in a regional context; b: The Myeik Archipelago; c: Lampi Island Complex; d: Thayawthadangyi Island Complex.

Data collection

Field work was carried out during November and December of 2017 and was a part of a broader socioeconomic study that focused on characterising small-scale fishers' livelihood behaviours, and small-scale shark fisheries in the Myeik Archipelago. Data were collected by Myeik University research staff, all of whom were trained to record socioeconomic and fisheries data. Interviews were conducted in Burmese language, or local Moken dialects through an additional translator. Prior to fieldwork, surveys were trialled in Myeik Township with mainland fishers to ensure interpretability of the survey and mapping exercises. Within the three communities, we conducted a series of structured, face-to-face surveys with active, mobile fishers to obtain quantitative data on the four socioeconomic factors that represented vulnerability (Supplementary Material 1). We targeted respondents through the intercept approach in locations that fishers gathered, and subsequently via snowball sampling. This sampling method was considered most appropriate to obtain a representative sample of fishers in the targeted communities, because it maximises interviews with hard-to-find individuals (Miller et al. 1997) such as semi-nomadic Moken fishers for whom no registry database was available. We also conducted a participatory mapping exercise with each fisher to identify the location of their three most frequented fishing grounds on a satellite image of the area. For these exercises, participants were also asked a series of questions concerning the spatio-temporal characteristics of their fishing grounds, their home village, and various other biophysical landmarks of the Myeik Archipelago to ensure their conceptualisation of the seascape and map were aligned. While a total of 120 participants were interviewed, we excluded incomplete datasets, leaving a total of 80 fishers contributing to this study (Lin Long n=26; Don Pale n=24; Makyone Gallet n=31).

Analysis

Material Style of Life

Twenty-six binary (absent/present) variables pertaining to household items (Material Style of Life, MSL) were obtained from each fisher. To ensure variability in the data we removed factors for which 80% of the participants' answers were alike. We then conducted a Pearson's correlation analysis and removed those factors correlated to over 0.8, leaving six variables: generator ownership, no access to electricity, boat ownership, roof material (metal), wall material (wood), wall material (thatch). As generators are only one type of electricity source (other sources include battery and solar), 'no access to electricity' implied that the individual had no access to any type of electricity whatsoever.

We conducted principal component analysis of a covariant matrix of the remaining six binary MSL variables using SPSS (v.25) (Pollnac and Crawford 2000). Kaiser-Meyer-Olkin's measure of sampling adequacy was 0.62, and Bartlett's test of sphericity was significant ($\chi 2 = 146.16$, $p = < .01$), indicating that the data were well suited for a principal component analysis (Field 2018). Factor loadings greater than 0.4 were retained for interpretation in accordance with Fornell and Larcker (1981). We retained

174 the rescaled Component One because it accounted for 40% of the variance (Supplementary Material 2).
175 We interpreted this component to highlight where an individual fell on the wealth spectrum. Those with
176 high MSL were characterised as being most wealthy: owned a generator, owned a boat, and had a house
177 made from non-degrading materials. Those with a low MSL score were least wealthy because they were
178 less likely to have access to electricity, own a boat or have a house made from non-degrading materials.
179 Component scores for the 80 individual fishers were then used to represent wealth.
180
181 *Livelihood Impact Potential*
182 We generated a Livelihood Impact Potential Index (LIPI) score for each individual small-scale fisher
183 based on data obtained for each of the four socioeconomic factors (Table 1). We adjusted the factor
184 outputs so that they were consistent in directional influence on vulnerability (i.e. low vulnerability
185 would entail high livelihood diversity, high education, low age and high MSL). Therefore, we reversed
186 the results for age. We standardised each factor on a scale of 0-1, then summed the standardised scores,
187 and divided the result by four to develop an LIPI score between 0 and 1. To test if the LIPI was sensitive
188 to any one particular factor, we conducted a sensitivity analysis by varying the value of each factor by
189 10% and monitoring resulting changes in the LIPI (Hamylton, 2017). A low LIPI score represented
190 individuals facing the fewest challenges with regards to vulnerability in the face of MPA-associated
191 livelihood restrictions. A high LIPI score represented individuals with the greatest challenges in
192 adapting to MPA-associated livelihood restrictions.

193 Each fisher's annotated satellite image was scanned and georeferenced to digitise their most frequented
194 fishing grounds. ESRI ArcGIS version 10.3 was used to attribute each fisher's LIPI score to their
195 associated fishing grounds. Fishing ground polygons overlapped, so *Union* and *Spatial Join* tools were
196 used to quantify the number of fishers who used each area (i.e. fishing pressure) and to calculate the
197 average LIPI value of all fishers who operate in each area. This enabled us to identify the areas that
198 would be most detrimental to fishers' livelihoods if they were restricted from use due to an MPA.

199 **3. Results & Discussion**
200 In the following, we describe how the LIPI can be used to support MPA planners to create MPAs that
201 limit negative impacts on the most vulnerable small-scale fishers, using an example from Lampi NMP.
202 ***3.1 Livelihood Impact Potential Index (LIPI)***
203 The LIPI is a composite score based on four local-level socioeconomic factors that describe the degree
204 to which a small-scale fisher is vulnerable to MPA-related restrictions on their livelihoods. Across the
205 80 fishers in our sample, mean values for the socioeconomic factors were: age =41.89 years
206 (SD=13.19); education =3.37 years of formal schooling (SD=0.34); livelihood diversity =1.41
207 livelihood strategies (SD=0.06); wealth =0.41 MSL (SD=0.02). Mean LIPI score was 0.35 (SD=0.02)
208 (Figure 2). Our sensitivity analysis showed that the mean LIPI score for each of the factor value
209 iterations remained within 10% of the combined LIPI score (Supplementary Material 3). This suggests

that LIPI is a robust measure and is not overly skewed by any particular factor. By attributing each fisher's LIPI score to their fishing ground(s) we were able to spatially identify areas that would be most detrimental to fishers if they were restricted from fishing there. Mean LIPI scores for overlapping fishing grounds were used to highlight areas where, on average, fishers would be least likely to adapt to MPA-related restrictions (Figure 3).

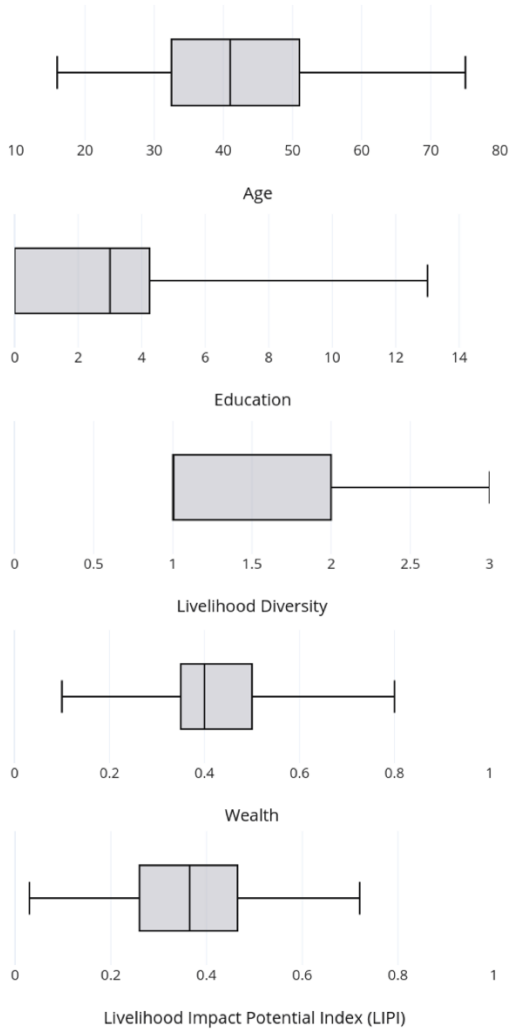

Figure 2. Spread of input socioeconomic factors (actual results) and Livelihood Impact Potential Index (LIPI) amongst small-scale fishers in the Myeik Archipelago. Boxplot displays values for minimum, first quartile, median, third quartile, and maximum scores for each factor and the LIPI.

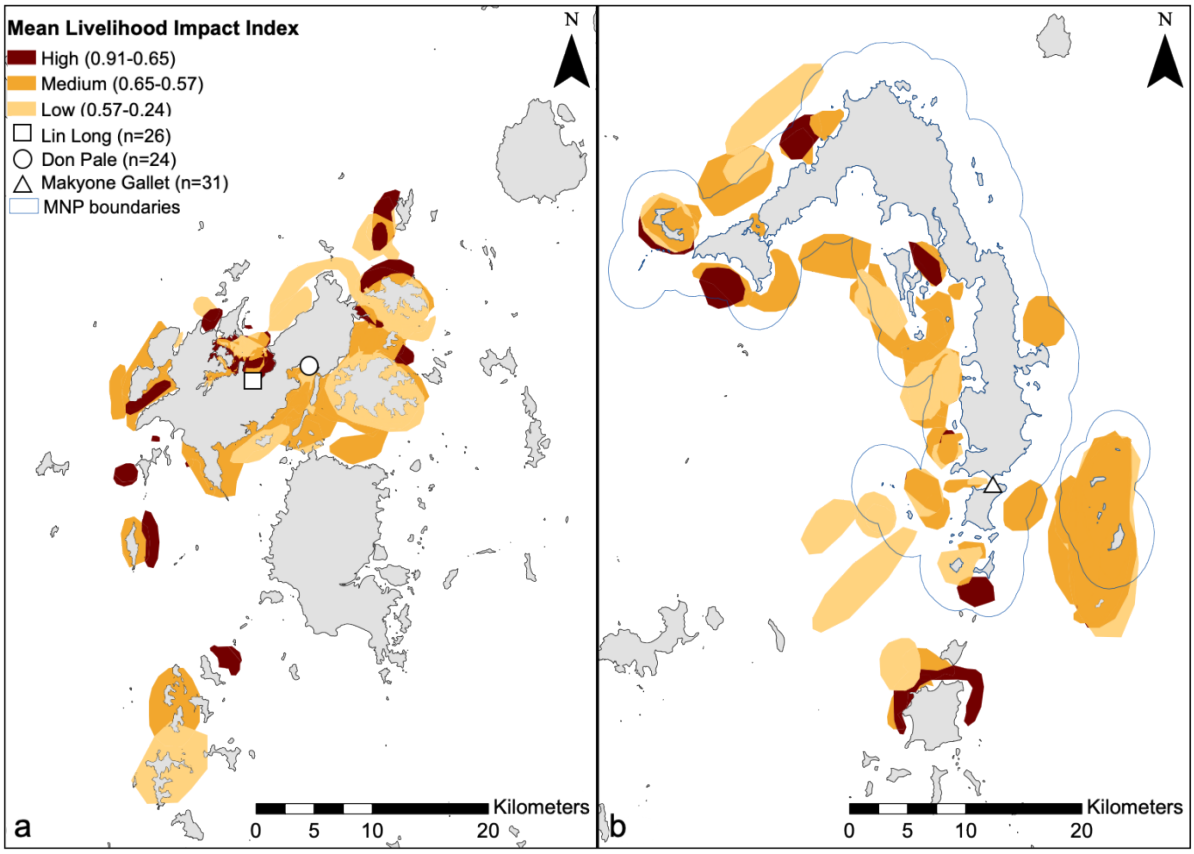

Figure 3. Mean Livelihood Impact Potential Index (LIPI) for identified fishing grounds in the Myeik Archipelago. a: Mean LIPI for small-scale fishers in Thayawthadangyi (Lin Long and Don Pale (total n=50)); b: Mean LIPI for small-scale fishers in Lampi (Makyone Gallet (n=31)).

3.2 Vulnerability of Fishers in the Myeik Archipelago

All of the fishers interviewed in this study used three or fewer livelihood strategies and had generally low education levels (Figure 2), indicating a generally low propensity for livelihood diversification. While this result highlights characteristics typical of many small-scale fishing communities (e.g. Mohamed Shaffril et al. 2017), the other two socioeconomic attributes varied more among fishers. Those individuals with a low LIPI score were characterised as being slightly more educated and having slightly more diverse livelihood strategies. However, the important variation was that individuals with low LIPI scores were most wealthy and youngest. These attributes describe fishers with the greatest ability to adapt a livelihood strategy to cope with MPA-associated restrictions to their fishing grounds. While this does not imply that these fishers should not be supported or that their livelihood needs should be disregarded, research has shown that fishers are more likely to perceive benefits from MPAs when they are wealthier, regardless of whether they have one or multiple livelihood strategies (MacNeil and Cinner 2013). Furthermore, other, comparable studies have shown that more wealthy individuals in communities are more likely to be positioned such that they are influential in policy-related decision making processes and benefit from local government arrangements (Adger and Kelly 1999, Christie

2004). This positioning coupled with youth and education can signify that an individual will be less risk-averse in exploring new livelihood opportunities, and will be better equipped with the tools to adapt to restriction on fishing from the outset (Gurney et al. 2015). Conversely, those individuals who scored highly on the LIPI are likely to require the greatest support if their livelihood activities are restricted as a result of no-take MPAs. Less wealthy individuals are more likely to perceive a livelihood benefit from MPAs when they are involved actively in decision making (MacNeil and Cinner 2013), so effort should be made to engage with these individuals in the MPA planning process. Moreover, if their fishing activities are to be restricted, these individuals are likely to need more time to adapt to and understand the MPA process, and may require assistance in diversification of livelihoods, investments in education, and developing forums to maintain and foster ecological knowledge.

4.2 Operationalising LIPI

While the aforementioned results describe the varying socioeconomic characteristics of small-scale fishers, it is useful from a marine spatial planning perspective to link these characteristics to the individuals' fishing grounds. By assigning fishers' LIPI scores to fishing grounds, we were able to discern the potential impact an MPA could have on individuals' livelihoods, depending on its location. When coupled with information on fishing concentration (i.e. number of fishers' who identify that area as one of their three most frequented sites), sites can be identified where MPAs are most likely to have biodiversity benefits, and least likely to restrict fishing activities of highly vulnerable individuals. To illustrate, we highlight three areas within Lampi NMP that represent varying LIPI milieus (Figure 4).

In area 'A' the average fisher has a higher LIPI value, reflecting general high levels of vulnerability. If regulations within Lampi were to restrict access to this area, then the most vulnerable fishers will be most compromised. These fishers are likely to be pushed further into poverty traps (Cinner et al. 2012) or will simply not comply with restrictive legislation out of necessity (Ostrom 2007). In addition, fishing concentration within this ground is low (i.e. less than four fishers identified this space as a fishing ground), meaning that benefits to biodiversity resulting from restricting access are likely to be minimal. Lampi NMP planners could choose to re-evaluate the importance of protecting this area or consider a zonation that supports these fishers by allocating specific fishing rights to high LIPI fishers. This would allow for both ecological and socioeconomic benefits, and potentially increase support for the NMP. In area 'B' a low average LIPI score for fishers in this area implies most fishers will be relatively more capable of adjusting to no-take restrictions (Figure 4a). However, given the low fishing concentration (Figure 4b), biodiversity benefits might also be low, suggesting that it could be unnecessary to devote resources to protecting such an area. Rather, an optimal area to restrict access is one where average LIPI is low, and fishing concentration is high, which should in turn promote positive impacts for biodiversity while minimising negative impacts on more vulnerable small-scale fishers. In area 'C' the average LIPI is low, suggesting a general ability for fishers to adjust to restrictions, and fishing concentration is high, indicating substantial benefits to biodiversity if fishing activity were removed.

NMP planners can identify communities where fishers within area 'C' that are on the lower end of the LIPI spectrum live (e.g. outliers or bottom quartile), and develop programs to support them appropriately throughout the MPA implementation process (e.g. livelihood diversification, and investments in education. Since targeting individuals based on their LIPI scores could be a sensitive issue, MPA planners should make mindful of this, for example by having a voluntary program for all fishers fishing in those zones so people can opt in or out rather than singling out individuals. In addition, LIPI scores are unlikely to remain static as associated measures such as wealth may change over time. As such, MPA planners should be mindful of this and attempt to re-evaluate the status of vulnerable fishers where possible.

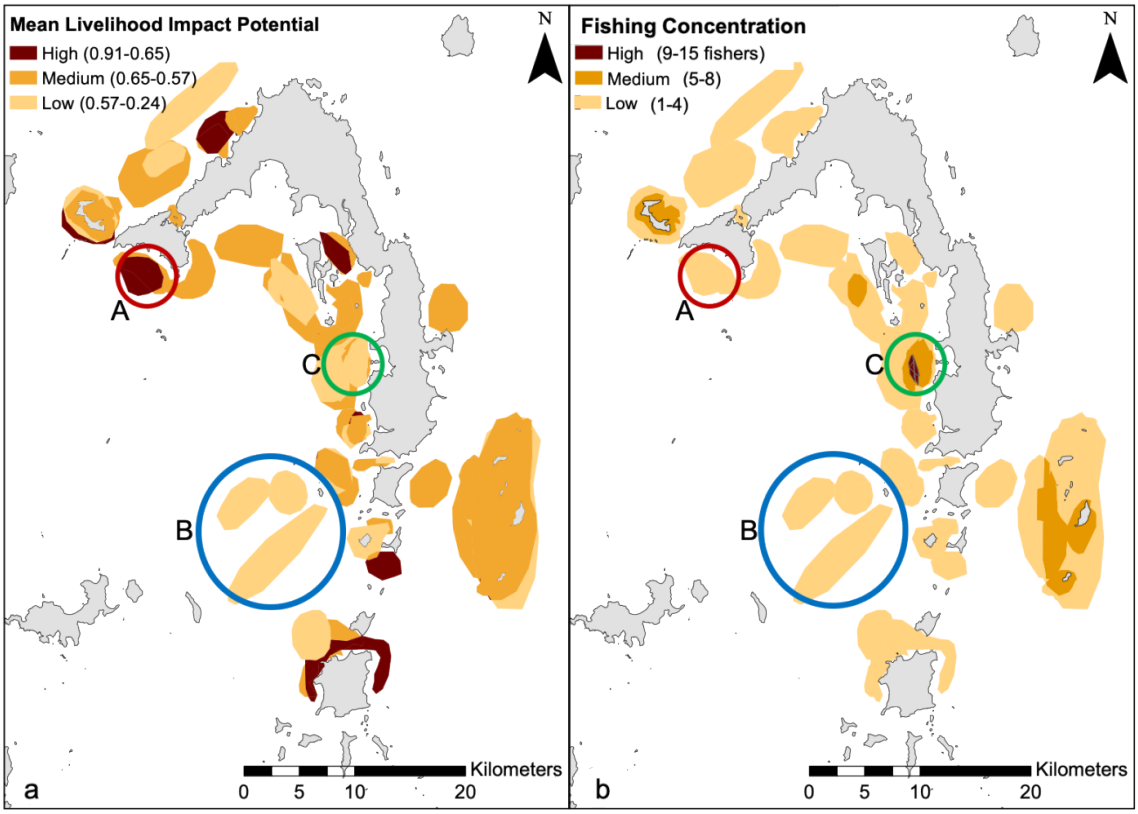

Figure 4. Mean LIPI values (a) compared to fishing concentration (b) of small-scale fishers from Makyone Gallet. Area A highlights an area with high LIPI and low fishing concentration, suggesting that no-take MPAs located here would have limited biodiversity impact and would negatively impact many of the more vulnerable people in the community. Area B highlights an area with low LIPI and low fishing concentration, suggesting that most fishers will be relatively more capable of adapting to no-take MPA restrictions however, biodiversity benefits will be low due to low fishing concentration. Area C highlights low LIPI and high fishing concentration, suggesting that a no-take MPA placed here would maximise biodiversity impact whilst having livelihood impacts only on the least vulnerable people within the community.

4.3 Implications for MPA planners

297 Understanding how MPAs impact small-scale fishers is fundamental to ensuring that MPAs are
298 designed to have equitable benefits, and to promote biodiversity benefits through increased likelihood
299 of compliance with MPA legislation (Day 2017, Giakoumi et al. 2018). Public participation in the MPA
300 planning process is increasingly legally required in many places, including Myanmar, and widely
301 advocated in the academic and policy literature, not only as a means to minimise negative impacts on
302 small-scale fishers, but also to build public trust and support for MPAs and decision makers (CBD
303 2010, FAO 2015, Day 2017, Giakoumi et al. 2018). While at times it might be unrealistic to identify
304 the needs of every individual in every fishing community, it is vital to recognise that not all small-scale
305 fishers will be equally impacted by MPAs, particularly in socially and economically heterogeneous
306 locations such as the Myeik Archipelago. The LIPI offers a means for systematically identifying where
307 resources to support vulnerable fishers could be allocated to benefit particular vulnerable fishers, with
308 application alongside a stakeholder consultation process. Figure 5 indicates where considerations related
309 to the LIPI might be included the MPA planning process.

310 While the LIPI helps to identify highly vulnerable individuals, it is worth noting that actions to improve
311 livelihood diversification have often failed in developing countries (Sievanen et al. 2005), with poverty
312 and old age being critical obstacles (MacNeil and Cinner 2013). The combination of these attributes in
313 high LIPI individuals suggests a group of people who will have particular problems in adapting to
314 restrictions on their fishing grounds. Diversification might not be an option for these fishers if they are
315 so profoundly trapped by poverty that trying an alternative livelihood strategy will be unrealistic
316 without additional support or safeguarding. In addition, the promotion of alternative livelihoods is
317 sometimes based on several assumptions, including that fishers are willing to forfeit fishing in favour
318 of other livelihood opportunities, and that if they do so, pressure will be reduced on fisheries (Sievanen
319 et al. 2005). Therefore, MPA practitioners might consider whether they should, in fact, place an MPA
320 in an area where there is a general high LIPI context. If they must, planners might choose a less
321 restrictive zonation strategy rather than 'no-take', that allocates specific fishing rights some fishers (e.g.
322 local-use zone) or fishing practices (e.g. hang-line fishing) within these grounds, and restricts other
323 users such as commercial fishers, or destructive fishing practices (e.g. long-line fishing) thereby
324 releasing pressure on these areas while simultaneously gaining support for MPAs.

325 Finally, though the LIPI presents a fine-scale indicator of adaptive capacity of small-scale fishing
326 communities, the index can be most beneficial when used alongside biological considerations such as
327 location of threatened ecosystems, and information about commercial fisheries that operate in the same
328 space. Furthermore, while the LIPI is a quantitative index based on objective factors that provides some
329 context for equitable MPA planning, planners should not neglect to include other socioeconomic
330 considerations (e.g. local context, and political and economic drivers) within the spatial MPA design
331 process. It will be particularly important for planners to recognise and consider other, more subjective
332 factors, that are not captured within the LIPI. This holistic approach to understanding an area's

socioeconomic and biophysical context will support MPA planners in making well-informed decisions about conservation, tailored to the unique context of each small-scale fishing community.

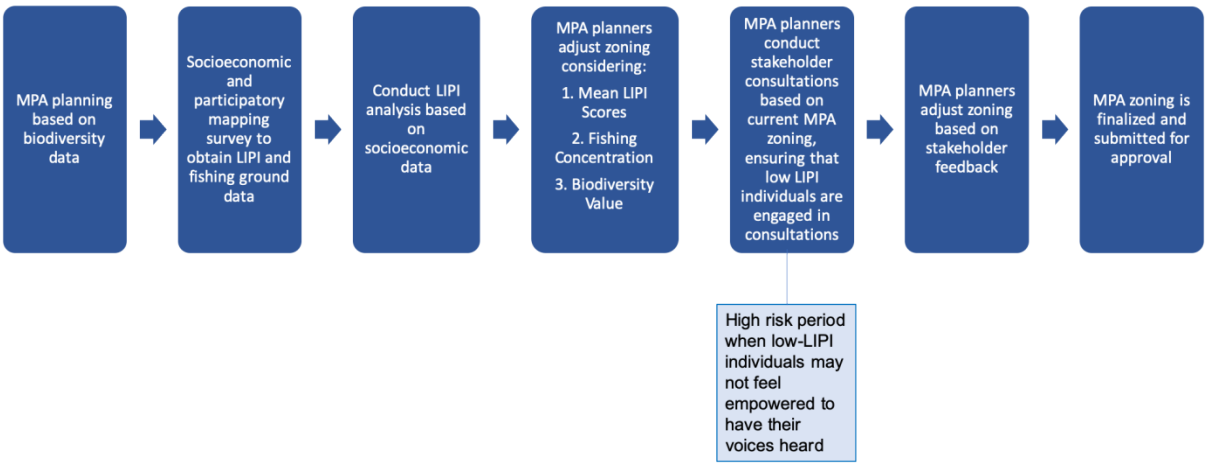

Figure 5. Flow diagram of decisions and for MPA planning using socioeconomic and biodiversity data, indicating where considerations related to the LIPI might be included.

4.4 Conclusion

Small-scale fishers across the globe are facing imminent threats and challenges to their livelihoods. Whilst MPAs offer the potential to support fisheries production, a failure to recognise the varying levels of vulnerability of many small-scale fishers means that well-meaning efforts to conserve resources can adversely impact the most vulnerable fishers in unintentional ways (Bennett and Dearden 2014). In this study, we developed a systematic and spatially explicit method to identify those individuals most vulnerable to being negatively impacted by no-take MPAs through an index that represents individual-level vulnerability to MPA restrictions. When used alongside ecological and commercial fishing data, the LIPI can support planners in designing local-scale MPAs that maximise positive impact on biodiversity, and minimise adverse impacts on the most vulnerable fishers in a community.

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Highlights

* MPAs often adversely impact fishers if local level vulnerability is not considered
* Linking level of vulnerability to a fishing grounds supports conservation planning
* Fishers with high vulnerability should be supported if their grounds are restricted
* Including vulnerability in MPA planning supports equity in fishing communities

Marine Protected Areas (MPAs) have the potential to support small-scale fishers in managing their resources. However, a general failure to consider the varying levels of vulnerability of fishers has resulted in MPAs that, often unintentionally, adversely impact small-scale fishers. Furthermore, when fishers lack the capacity to adapt to MPA-related changes, MPAs may fail to meet conservation objectives because fishers do not comply with MPA regulations. In this study, we developed a systematic method to identify individuals who are most vulnerable to being negatively impacted by no-take MPAs through an index that represents individual-level vulnerability. We designed a method for identifying these individuals based on four socioeconomic factors pertaining to vulnerability to MPA changes: livelihood diversity, education, age and wealth, then applied this method in two socially and economically heterogeneous communities in Myanmar's Myeik Archipelago. We used empirical data collected from 80 small-scale fishers in this area to represent each factor, then generated a local-level 'livelihood impact potential index' (LIPI) that reflects the degree to which a no-take MPA would impact an individual fisher's ability to support his or her livelihood. When attributed to each fisher's most frequented fishing ground, the LIPI can identify locations where no-take MPAs would be most detrimental to small-scale fishers' livelihoods based on their levels of vulnerability. The LIPI can thus be used alongside ecological and commercial fishing data to support planners in designing local-scale MPAs that maximise positive impact on biodiversity and minimise adverse impacts on the most vulnerable fishers in a community.

Biological Conservation

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Mitigating negative livelihood impacts of no-take MPAs on small-scale fishers

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1. Introduction

Ninety-seven percent of small-scale fishers live in least developed countries (WB 2012). The value of marine resources to these fishers lies not only in employment and nutrition (Kawarazuka and Béné 2010, Kawarazuka and Béné 2011, Barnes-Mauthe et al. 2013), but also in cultural, social and bequest values, that operate synergistically in their contribution to fishers' wellbeing and livelihoods (Béné 2006, Salas et al. 2007, O'Garra 2009).

Since fish biomass caught from the world's oceans peaked in the late 1980s, global fish production has declined at an unprecedented rate (Pauly et al. 1998). Overexploitation of marine resources has resulted in adverse ecological consequences (e.g. Pauly et al. 1998, Cinner and McClanahan 2006, Januchowski-Hartley et al. 2015), and subsequent negative impacts on the livelihoods of many marine fishers (Clausen and York 2008). Negative impacts are amplified for small-scale fishers in developing countries who often operate in open-access and low-productivity fisheries, and are in perpetual competition with commercial fishing fleets for a shared marine resource (Andrew et al. 2007).

Galvanised by increasing pressure on marine fisheries and competition between resource users, international attention has focused on mechanisms to protect marine ecosystems while simultaneously seeking opportunities to support the sustainable use of marine resources. Marine protected areas (MPAs) have been endorsed as one means to achieve the dual objectives of biodiversity conservation and fisheries management (Roberts et al. 2001, Garcia et al. 2014). Over time, no-take MPAs can increase fish biomass, and "spillover" into adjacent open-access waters (NRC 2001, Topor et al. 2019). MPA zoning can also enhance food security for specific fishing subgroups by reallocating fishing rights which thereby reduces local competition for fishing resource, such as the restriction of trawl vessels to allow only for artisanal fishers in certain zones (Christie et al. 1994, Himes 2003, Mascia et al. 2010).

While MPAs have the potential to benefit small-scale fishers, considerations concerning how capable local resource users are to adapt to MPA-related restrictions, and hence how vulnerable they are to negative consequences, are often overlooked (Mizrahi et al. 2018, Mizrahi 2019). Vulnerability can be defined as the state of susceptibility to harm from perturbations (Adger 2006). A person's vulnerability is influenced in part by his or her ability to adapt to losses or alternations in resource access, and hence their potential to suffer negative consequences related to a change such as the establishment of an MPA (Adger and Vincent 2005, Gallopín 2006). While some individual fishers might be in a position to adapt to livelihood restrictions, others are more vulnerable to MPA-related restrictions due to socioeconomic limitations related to wealth, livelihood diversity, education and age (Cinner et al. 2009, Cinner and Bodin 2010, Launio et al. 2010, Setiawan et al. 2012, Gurney et al. 2015, Voyer et al. 2015 in Mizrahi et al. 2018). Fishers who are most wealthy are generally best placed to benefit from local government arrangements (Adger and Kelly 1999), and will often position themselves well in decision-making

situations (Christie 2004). These fishers also experience fewer risks associated with attempting a new livelihood activity which serves as a safeguard if access to fisheries resources is restricted (MacNeil and Cinner 2013). In contrast, less wealthy fishers with fewer livelihood strategies and low education levels are generally most likely to be negatively impacted by restriction on fisheries resources, and are less likely to have the skills to attempt new livelihood opportunities (Cinner et al. 2012). Furthermore, as age increases, opportunities to diversify livelihoods decrease (Cinner et al. 2012), as does openness to gaining new environmental knowledge (Gurney et al. 2015).

Perversely, poorly designed MPAs often end up negatively impacting the most vulnerable people, who are most immediately affected by new regulations. Restricting the resource use of the most vulnerable can manifest in poverty traps, a reinforcing mechanism whereby people find it challenging to escape poverty unless a significant amount of economic capital is made available (Azariadis and Stach 2005). This is particularly true in least developed and low-income countries in which many of the world's small-scale fishers operate, and where fisheries provide one of the few opportunities for protein and income. For cases where small-scale fishers are not well placed to adjust to MPA-related changes, adverse impacts on vulnerable fishers can also result in adverse consequences for biodiversity, with fishers failing to comply with MPA regulations unless strong enforcement is present (Ostrom 2007). Potential biodiversity gains from MPAs are therefore less likely in cases where policymakers fail to consider the local needs and context of small-scale fishers. For example, responding to threats of overexploitation and decline in fisheries, Thailand's government has implemented 16 National Marine Parks (NMPs) within its Andaman Sea territorial boundaries (Bennett and Dearden 2014). While these NMPs were intended to support conservation, the parks are also situated in areas close to many of the 621 small-scale fishing communities that inhabit the Andaman coastline (Panjarat 2008). Local fishers were prohibited from harvesting in their usual fishing grounds, and one study of small-scale fishers in areas adjacent to the NMPs found that they felt they could not support themselves if they were excluded from fishing in those areas (Bennett and Dearden 2014). While Thailand's NMPs might contribute to national-level protected area targets (CBD 2010), local perceptions of these NMPs are mostly negative in small-scale fishing and subsistence harvesting communities, where fishing activities are generally seen to be adversely impacted by NMPs. These perceptions have resulted in protected areas with low compliance and hence limited biodiversity benefits (Prasertcharoensuk et al. 2010, Bennett and Dearden 2014).

In most studies that consider the livelihood needs of fishers in MPA planning, socioeconomic factors are included in the form of reducing livelihood costs of conservation to stakeholder groups as one homogenous entity, such as commercial fishers (Richardson et al. 2006), or entire communities (Thiault et al. 2018). When applied at a local scale, these methods become problematic because they assume there is no variation between costs to different individuals within each stakeholder group, and can lead

to MPAs that have inequitable impacts on individuals. Inequitable distribution of costs and benefits within a community can manifest as 'elite capture' whereby elites use their positions of status and power to promote their own interests at the expense of others (Béné et al. 2009). Due to the social and economic heterogeneity of many small-scale fishing communities, the impacts of MPAs are likely to vary among fishers depending on individual levels of vulnerability. Furthermore, fishers from the same community visit a range of fishing grounds influenced by factors including equipment available (e.g. access to a motorised vessels), time available, level of experience, and traditional values (unpublished data). This introduces further spatial complexity into whom within a community will be most affected by an MPA, and has, to the best of our knowledge, not been addressed in previous studies.

In this study, we aimed to develop a systematic method to identify the optimal location for no-take MPAs so that they limit negative impacts on small-scale fishers with the highest levels of vulnerability to experiencing negative consequences from MPAs (heron referred to as 'vulnerability') within a community. We designed a method for identifying these individuals based on four socioeconomic factors related to vulnerability, a key characteristic that mediates people's vulnerability to change (adapted from Mizrahi et al. 2018), and applied this method in two socially and economically diverse communities in Myanmar's Myeik Archipelago. We used data collected from small-scale fishers in this area to represent each factor, then generated a local-level 'livelihood impact potential' index that reflects the degree to which a no-take MPA would impact an individual fisher's ability to support his or her livelihood. When this score is attributed to each fisher's most frequented fishing ground, the index can help identify locations where MPAs would be most detrimental to small-scale fishers' livelihoods based on their level of vulnerability.

2. Material and methods

2.1 Socioeconomic Factors

A systematic review conducted in Mizrahi et al. (2018) identified 17 socioeconomic factors influencing the nature and level of impacts that MPAs have on livelihoods. In that study and the present one, impact is defined as the outcome resulting from protection compared to a counterfactual scenario of no protection (Pressey et al. 2015). From the initial list of 17 factors, we identified four local-level factors relevant to an individual's vulnerability to MPA restrictions: *livelihood diversity, education, age*, and *wealth* (Table 1). In combination, these measures indicate the degree to which individual small-scale fishers' livelihoods would be impacted by a no-take MPA. We used empirical data obtained from surveys with 80 fishers in the Myeik Archipelago to represent these factors (Table 1).

Table 1. Socioeconomic factors (adapted from Mizrahi et al. 2018) that influence how small-scale fishers' livelihoods can be impacted by the establishment of MPAs. Refer to Mizrahi et al. 2018 for references to the original literature supporting how each socioeconomic factor can influence positive livelihood outcomes.

Socioeconomic Factor	Relationship with adaptive capacity	Survey Data
Livelihood diversity	Individuals with the fewest livelihood strategies are generally most likely to be negatively impacted by restriction of resources and are less likely to support MPAs if MPAs are perceived to reduce their access to food or income.	Total number of different occupations per individual
Education level	Formally schooled fishers are more likely to be aware of, understand and support conservation efforts such as MPAs, and have more skills to take on new livelihood opportunities.	Number of formal schooling years completed per individual
Age	Younger individuals have greater potential to gain environmental knowledge and have increased openness and opportunities to embrace change. Older individuals will more likely be negatively impacted by MPAs due to more risk associated with attempting a new livelihood strategy.	Age of the individual
Wealth	Individuals with lower wealth (represented here as household Material Style of Life) face greater challenges in adapting to restrictive legislation.	Factor score of household items of the individual representing Material Style of Life Index (Pollnac and Crawford 2000)

2.2 Ethics

This study was carried out under human ethics permit xxx. All participants provided oral consent to be interviewed. Prior to being interviewed, all respondents were informed of the purpose of the interview, the confidentiality of information provided, and the right to omit questions or end the interview at any stage.

2.3.1 Study site

This study draws on data from three fisheries-dependent communities located in the Myeik Archipelago in Southern Myanmar: Don Pale, Lin Long and Makyone Gallet (Figure 1). Myanmar's small-scale fishers operate in a general context of poverty, low education, ethnic diversity and strong dependence on fisheries (Schneider and Thiha 2014). Marine resources are a major contributor to food security, providing direct livelihoods for an estimated 1.4 million fishers (DoF 2017), with per capita consumptions remaining one of the highest in the world (FAO 2012). Fishing is the main source of livelihood for those living in the Myeik Archipelago, and can be characterised as a multi-gear, multi-species fishery with limited access to outside markets (Schneider and Thiha 2014). Furthermore, these fishers are from diverse ethnic backgrounds with varying historical association with the islands (Schneider and Thiha 2014). These diverse community characteristics represent a relevant case study to examine how the restriction of resource extraction would impact different individuals and inform how MPAs can be designed to minimise detrimental livelihood impacts on the most vulnerable community members.

In the Myeik Archipelago, MPAs are mostly in the inception stage of design and development. For example, in the south of the Myeik Archipelago, Lampi Marine National Park (MNP) is an IUCN category II MPA that theoretically functions through a top-down governance system in which the state controls management through laws and other regulations, with the dual objective of protection of biodiversity and sustainable human development (MOECAF 2014). While the park boundaries have been allocated and a draft zoning plan has been designed, management inputs are still in the early stages, resulting in minimal biodiversity or livelihood implications from the MNP to date (Dearden 2016).

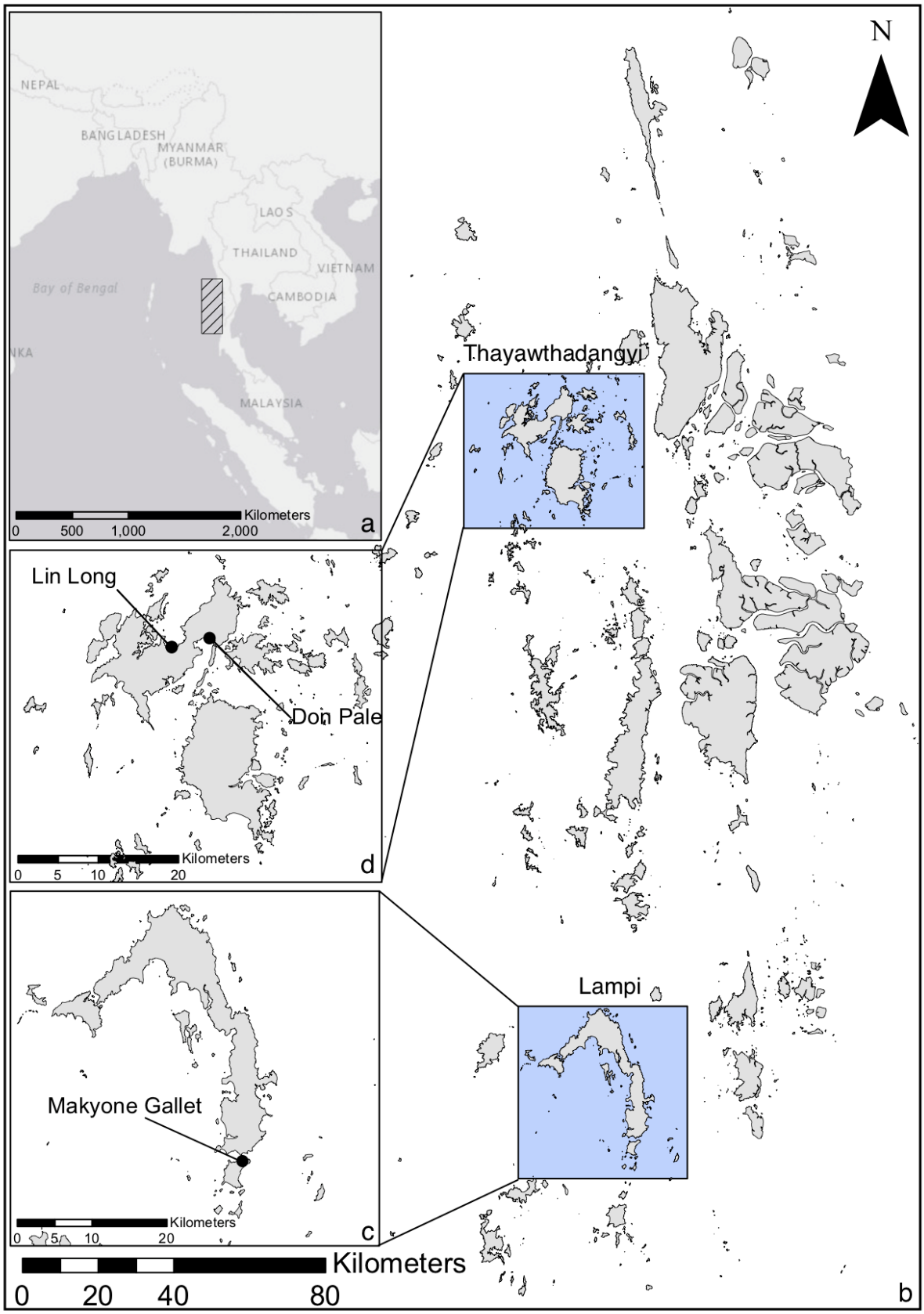

Figure 1. Map of the Myeik Archipelago highlighting three study sites in Don Pale, Lin Long and Makyone Gallet. a: Myanmar in a regional context; b: The Myeik Archipelago; c: Lampi Island Complex; d: Thayawthadangyi Island Complex.

Data collection

Field work was carried out during November and December of 2017 and was a part of a broader socioeconomic study that focused on characterising small-scale fishers' livelihood behaviours, and small-scale shark fisheries in the Myeik Archipelago. Data were collected by Myeik University research staff, all of whom were trained to record socioeconomic and fisheries data. Interviews were conducted in Burmese language, or local Moken dialects through an additional translator. Prior to fieldwork, surveys were trialled in Myeik Township with mainland fishers to ensure interpretability of the survey and mapping exercises. Within the three communities, we conducted a series of structured, face-to-face surveys with active, mobile fishers to obtain quantitative data on the four socioeconomic factors that represented vulnerability (Supplementary Material 1). We targeted respondents through the intercept approach in locations that fishers gathered, and subsequently via snowball sampling. This sampling method was considered most appropriate to obtain a representative sample of fishers in the targeted communities, because it maximises interviews with hard-to-find individuals (Miller et al. 1997) such as semi-nomadic Moken fishers for whom no registry database was available. We also conducted a participatory mapping exercise with each fisher to identify the location of their three most frequented fishing grounds on a satellite image of the area. For these exercises, participants were also asked a series of questions concerning the spatio-temporal characteristics of their fishing grounds, their home village, and various other biophysical landmarks of the Myeik Archipelago to ensure their conceptualisation of the seascape and map were aligned. While a total of 120 participants were interviewed, we excluded incomplete datasets, leaving a total of 80 fishers contributing to this study (Lin Long n=26; Don Pale n=24; Makyone Gallet n=31).

Analysis

Material Style of Life

Twenty-six binary (absent/present) variables pertaining to household items (Material Style of Life, MSL) were obtained from each fisher. To ensure variability in the data we removed factors for which 80% of the participants' answers were alike. We then conducted a Pearson's correlation analysis and removed those factors correlated to over 0.8, leaving six variables: generator ownership, no access to electricity, boat ownership, roof material (metal), wall material (wood), wall material (thatch). As generators are only one type of electricity source (other sources include battery and solar), 'no access to electricity' implied that the individual had no access to any type of electricity whatsoever.

We conducted principal component analysis of a covariant matrix of the remaining six binary MSL variables using SPSS (v.25) (Pollnac and Crawford 2000). Kaiser-Meyer-Olkin's measure of sampling adequacy was 0.62, and Bartlett's test of sphericity was significant ($\chi 2 = 146.16$, $p = < .01$), indicating that the data were well suited for a principal component analysis (Field 2018). Factor loadings greater than 0.4 were retained for interpretation in accordance with Fornell and Larcker (1981). We retained

174 the rescaled Component One because it accounted for 40% of the variance (Supplementary Material 2).
175 We interpreted this component to highlight where an individual fell on the wealth spectrum. Those with
176 high MSL were characterised as being most wealthy: owned a generator, owned a boat, and had a house
177 made from non-degrading materials. Those with a low MSL score were least wealthy because they were
178 less likely to have access to electricity, own a boat or have a house made from non-degrading materials.
179 Component scores for the 80 individual fishers were then used to represent wealth.
180
181 *Livelihood Impact Potential*
182 We generated a Livelihood Impact Potential Index (LIPI) score for each individual small-scale fisher
183 based on data obtained for each of the four socioeconomic factors (Table 1). We adjusted the factor
184 outputs so that they were consistent in directional influence on vulnerability (i.e. low vulnerability
185 would entail high livelihood diversity, high education, low age and high MSL). Therefore, we reversed
186 the results for age. We standardised each factor on a scale of 0-1, then summed the standardised scores,
187 and divided the result by four to develop an LIPI score between 0 and 1. To test if the LIPI was sensitive
188 to any one particular factor, we conducted a sensitivity analysis by varying the value of each factor by
189 10% and monitoring resulting changes in the LIPI (Hamylton, 2017). A low LIPI score represented
190 individuals facing the fewest challenges with regards to vulnerability in the face of MPA-associated
191 livelihood restrictions. A high LIPI score represented individuals with the greatest challenges in
192 adapting to MPA-associated livelihood restrictions.

193 Each fisher's annotated satellite image was scanned and georeferenced to digitise their most frequented
194 fishing grounds. ESRI ArcGIS version 10.3 was used to attribute each fisher's LIPI score to their
195 associated fishing grounds. Fishing ground polygons overlapped, so *Union* and *Spatial Join* tools were
196 used to quantify the number of fishers who used each area (i.e. fishing pressure) and to calculate the
197 average LIPI value of all fishers who operate in each area. This enabled us to identify the areas that
198 would be most detrimental to fishers' livelihoods if they were restricted from use due to an MPA.

199 **3. Results & Discussion**
200 In the following, we describe how the LIPI can be used to support MPA planners to create MPAs that
201 limit negative impacts on the most vulnerable small-scale fishers, using an example from Lampi NMP.
202 ***3.1 Livelihood Impact Potential Index (LIPI)***
203 The LIPI is a composite score based on four local-level socioeconomic factors that describe the degree
204 to which a small-scale fisher is vulnerable to MPA-related restrictions on their livelihoods. Across the
205 80 fishers in our sample, mean values for the socioeconomic factors were: age =41.89 years
206 (SD=13.19); education =3.37 years of formal schooling (SD=0.34); livelihood diversity =1.41
207 livelihood strategies (SD=0.06); wealth =0.41 MSL (SD=0.02). Mean LIPI score was 0.35 (SD=0.02)
208 (Figure 2). Our sensitivity analysis showed that the mean LIPI score for each of the factor value
209 iterations remained within 10% of the combined LIPI score (Supplementary Material 3). This suggests

that LIPI is a robust measure and is not overly skewed by any particular factor. By attributing each fisher's LIPI score to their fishing ground(s) we were able to spatially identify areas that would be most detrimental to fishers if they were restricted from fishing there. Mean LIPI scores for overlapping fishing grounds were used to highlight areas where, on average, fishers would be least likely to adapt to MPA-related restrictions (Figure 3).

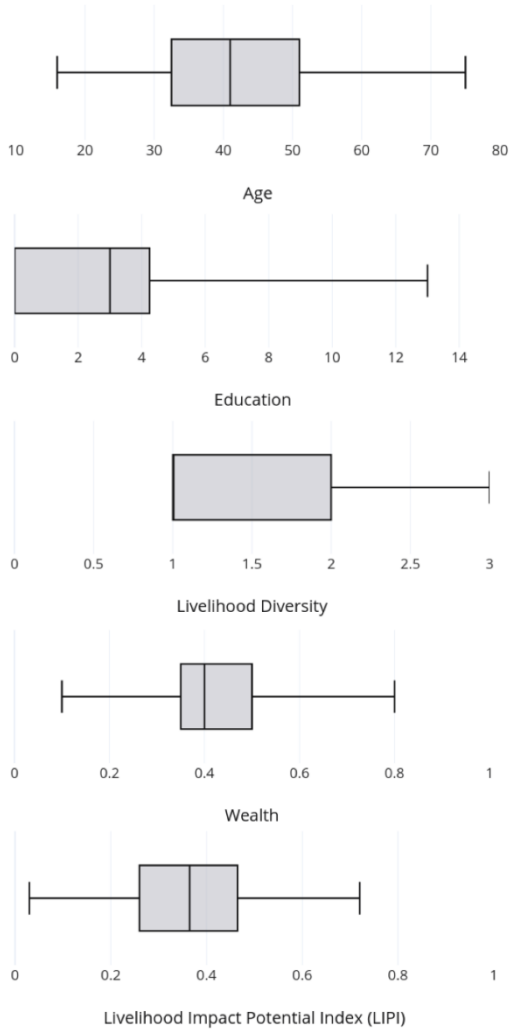

Figure 2. Spread of input socioeconomic factors (actual results) and Livelihood Impact Potential Index (LIPI) amongst small-scale fishers in the Myeik Archipelago. Boxplot displays values for minimum, first quartile, median, third quartile, and maximum scores for each factor and the LIPI.

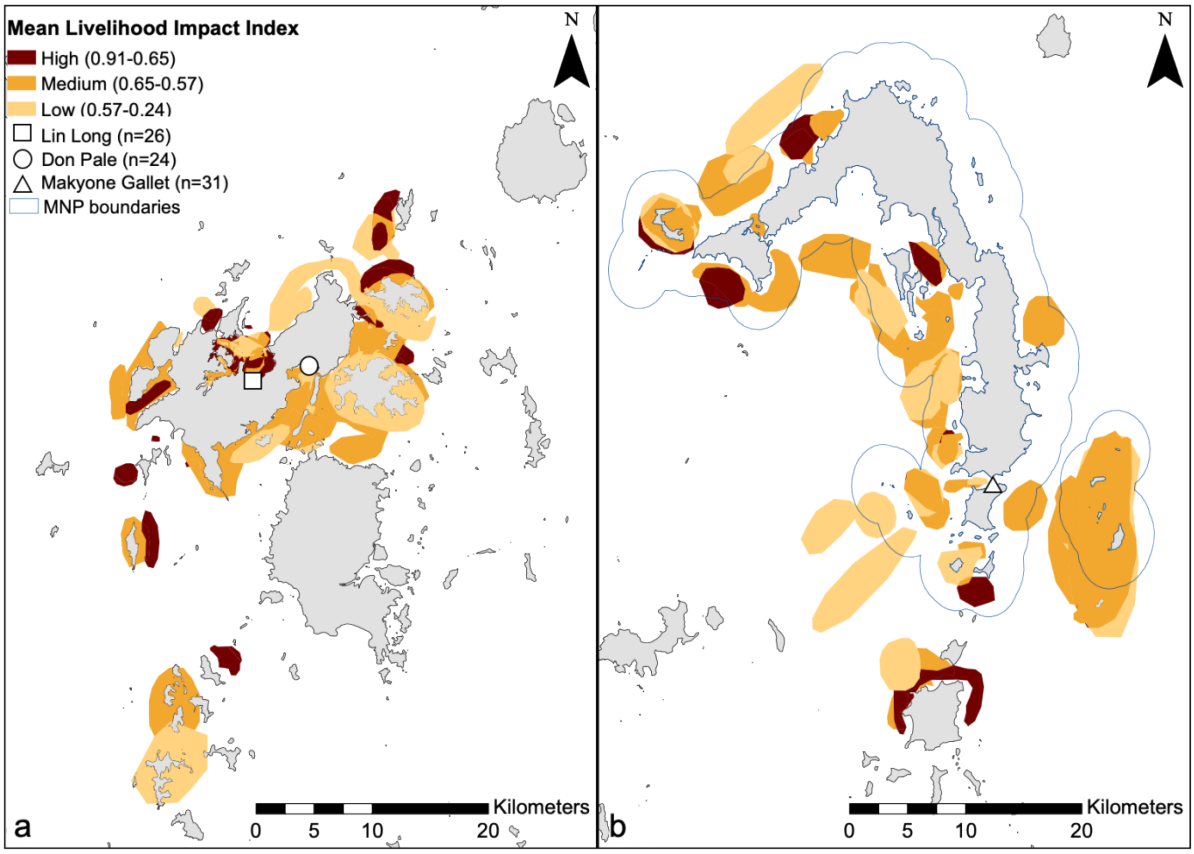

Figure 3. Mean Livelihood Impact Potential Index (LIPI) for identified fishing grounds in the Myeik Archipelago. a: Mean LIPI for small-scale fishers in Thayawthadangyi (Lin Long and Don Pale (total n=50)); b: Mean LIPI for small-scale fishers in Lampi (Makyone Gallet (n=31)).

3.2 Vulnerability of Fishers in the Myeik Archipelago

All of the fishers interviewed in this study used three or fewer livelihood strategies and had generally low education levels (Figure 2), indicating a generally low propensity for livelihood diversification. While this result highlights characteristics typical of many small-scale fishing communities (e.g. Mohamed Shaffril et al. 2017), the other two socioeconomic attributes varied more among fishers. Those individuals with a low LIPI score were characterised as being slightly more educated and having slightly more diverse livelihood strategies. However, the important variation was that individuals with low LIPI scores were most wealthy and youngest. These attributes describe fishers with the greatest ability to adapt a livelihood strategy to cope with MPA-associated restrictions to their fishing grounds. While this does not imply that these fishers should not be supported or that their livelihood needs should be disregarded, research has shown that fishers are more likely to perceive benefits from MPAs when they are wealthier, regardless of whether they have one or multiple livelihood strategies (MacNeil and Cinner 2013). Furthermore, other, comparable studies have shown that more wealthy individuals in communities are more likely to be positioned such that they are influential in policy-related decision making processes and benefit from local government arrangements (Adger and Kelly 1999, Christie

2004). This positioning coupled with youth and education can signify that an individual will be less risk-averse in exploring new livelihood opportunities, and will be better equipped with the tools to adapt to restriction on fishing from the outset (Gurney et al. 2015). Conversely, those individuals who scored highly on the LIPI are likely to require the greatest support if their livelihood activities are restricted as a result of no-take MPAs. Less wealthy individuals are more likely to perceive a livelihood benefit from MPAs when they are involved actively in decision making (MacNeil and Cinner 2013), so effort should be made to engage with these individuals in the MPA planning process. Moreover, if their fishing activities are to be restricted, these individuals are likely to need more time to adapt to and understand the MPA process, and may require assistance in diversification of livelihoods, investments in education, and developing forums to maintain and foster ecological knowledge.

4.2 Operationalising LIPI

While the aforementioned results describe the varying socioeconomic characteristics of small-scale fishers, it is useful from a marine spatial planning perspective to link these characteristics to the individuals' fishing grounds. By assigning fishers' LIPI scores to fishing grounds, we were able to discern the potential impact an MPA could have on individuals' livelihoods, depending on its location. When coupled with information on fishing concentration (i.e. number of fishers' who identify that area as one of their three most frequented sites), sites can be identified where MPAs are most likely to have biodiversity benefits, and least likely to restrict fishing activities of highly vulnerable individuals. To illustrate, we highlight three areas within Lampi NMP that represent varying LIPI milieus (Figure 4).

In area 'A' the average fisher has a higher LIPI value, reflecting general high levels of vulnerability. If regulations within Lampi were to restrict access to this area, then the most vulnerable fishers will be most compromised. These fishers are likely to be pushed further into poverty traps (Cinner et al. 2012) or will simply not comply with restrictive legislation out of necessity (Ostrom 2007). In addition, fishing concentration within this ground is low (i.e. less than four fishers identified this space as a fishing ground), meaning that benefits to biodiversity resulting from restricting access are likely to be minimal. Lampi NMP planners could choose to re-evaluate the importance of protecting this area or consider a zonation that supports these fishers by allocating specific fishing rights to high LIPI fishers. This would allow for both ecological and socioeconomic benefits, and potentially increase support for the NMP. In area 'B' a low average LIPI score for fishers in this area implies most fishers will be relatively more capable of adjusting to no-take restrictions (Figure 4a). However, given the low fishing concentration (Figure 4b), biodiversity benefits might also be low, suggesting that it could be unnecessary to devote resources to protecting such an area. Rather, an optimal area to restrict access is one where average LIPI is low, and fishing concentration is high, which should in turn promote positive impacts for biodiversity while minimising negative impacts on more vulnerable small-scale fishers. In area 'C' the average LIPI is low, suggesting a general ability for fishers to adjust to restrictions, and fishing concentration is high, indicating substantial benefits to biodiversity if fishing activity were removed.

NMP planners can identify communities where fishers within area 'C' that are on the lower end of the LIPI spectrum live (e.g. outliers or bottom quartile), and develop programs to support them appropriately throughout the MPA implementation process (e.g. livelihood diversification, and investments in education). Since targeting individuals based on their LIPI scores could be a sensitive issue, MPA planners should remain sensitive to this, for example by having a voluntary program for all fishers fishing in those zones so people can opt in or out rather than singling out individuals. In addition, LIPI scores are unlikely to remain static as associated measures such as wealth may change over time. As such, MPA planners should be mindful of this and attempt to re-evaluate the status of vulnerable fishers where possible.

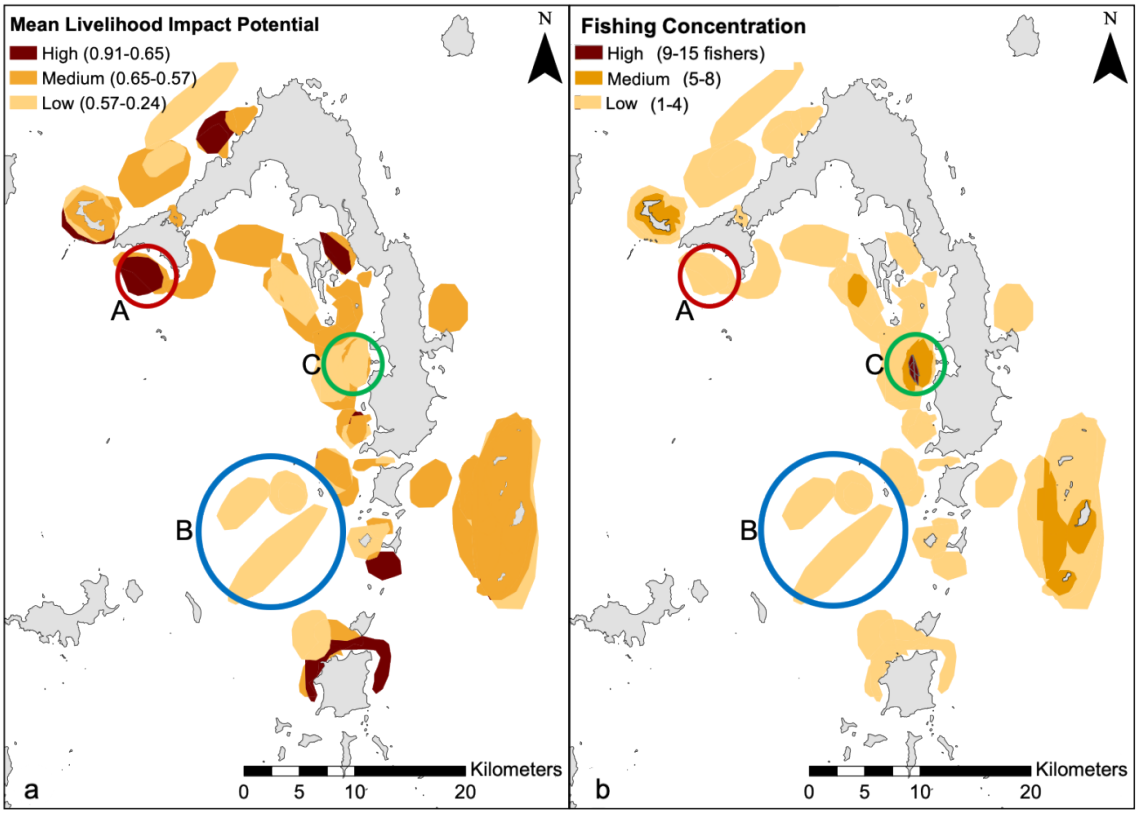

Figure 4. Mean LIPI values (a) compared to fishing concentration (b) of small-scale fishers from Makyone Gallet. Area A highlights an area with high LIPI and low fishing concentration, suggesting that no-take MPAs located here would have limited biodiversity impact and would negatively impact many of the more vulnerable people in the community. Area B highlights an area with low LIPI and low fishing concentration, suggesting that most fishers will be relatively more capable of adapting to no-take MPA restrictions however, biodiversity benefits will be low due to low fishing concentration. Area C highlights low LIPI and high fishing concentration, suggesting that a no-take MPA placed here would maximise biodiversity impact whilst having livelihood impacts only on the least vulnerable people within the community.

4.3 Implications for MPA planners

297 Understanding how MPAs impact small-scale fishers is fundamental to ensuring that MPAs are
298 designed to have equitable benefits, and to promote biodiversity benefits through increased likelihood
299 of compliance with MPA legislation (Day 2017, Giakoumi et al. 2018). Public participation in the MPA
300 planning process is increasingly legally required in many places, including Myanmar, and widely
301 advocated in the academic and policy literature, not only as a means to minimise negative impacts on
302 small-scale fishers, but also to build public trust and support for MPAs and decision makers (CBD
303 2010, FAO 2015, Day 2017, Giakoumi et al. 2018). While at times it might be unrealistic to identify
304 the needs of every individual in every fishing community, it is vital to recognise that not all small-scale
305 fishers will be equally impacted by MPAs, particularly in socially and economically heterogeneous
306 locations such as the Myeik Archipelago. The LIPI offers a means for systematically identifying where
307 resources to support vulnerable fishers could be allocated to benefit particular vulnerable fishers, with
308 application alongside a stakeholder consultation process. Figure 5 indicates where considerations related
309 to the LIPI might be included the MPA planning process.

310 While the LIPI helps to identify highly vulnerable individuals, it is worth noting that actions to improve
311 livelihood diversification have often failed in developing countries (Sievanen et al. 2005), with poverty
312 and old age being critical obstacles (MacNeil and Cinner 2013). The combination of these attributes in
313 high LIPI individuals suggests a group of people who will have particular problems in adapting to
314 restrictions on their fishing grounds. Diversification might not be an option for these fishers if they are
315 so profoundly trapped by poverty that trying an alternative livelihood strategy will be unrealistic
316 without additional support or safeguarding. In addition, the promotion of alternative livelihoods is
317 sometimes based on several assumptions, including that fishers are willing to forfeit fishing in favour
318 of other livelihood opportunities, and that if they do so, pressure will be reduced on fisheries (Sievanen
319 et al. 2005). Therefore, MPA practitioners might consider whether they should, in fact, place an MPA
320 in an area where there is a general high LIPI context. If they must, planners might choose a less
321 restrictive zonation strategy rather than 'no-take', that allocates specific fishing rights some fishers (e.g.
322 local-use zone) or fishing practices (e.g. hang-line fishing) within these grounds, and restricts other
323 users such as commercial fishers, or destructive fishing practices (e.g. long-line fishing) thereby
324 releasing pressure on these areas while simultaneously gaining support for MPAs.

325 Finally, though the LIPI presents a fine-scale indicator of adaptive capacity of small-scale fishing
326 communities, the index can be most beneficial when used alongside biological considerations such as
327 location of threatened ecosystems, and information about commercial fisheries that operate in the same
328 space. Furthermore, while the LIPI is a quantitative index based on objective factors that provides some
329 context for equitable MPA planning, planners should not neglect to include other socioeconomic
330 considerations (e.g. local context, and political and economic drivers) within the spatial MPA design
331 process. It will be particularly important for planners to recognise and consider other, more subjective
332 factors, that are not captured within the LIPI (e.g. wellbeing Seara et al. 2017). This holistic approach

to understanding an area's socioeconomic and biophysical context will support MPA planners in making well-informed decisions about conservation, tailored to the unique context of each small-scale fishing community.

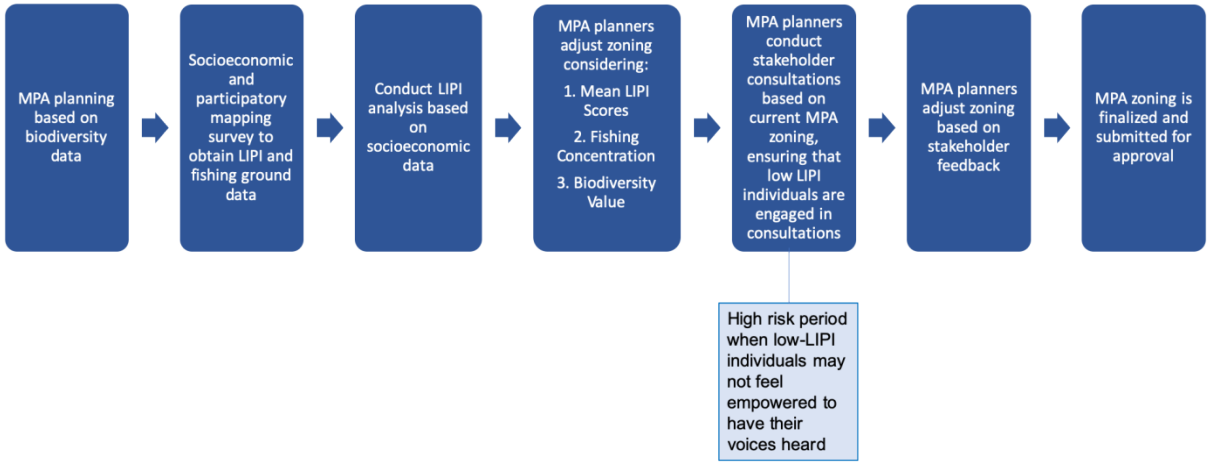

Figure 5. Flow diagram of decisions and for MPA planning using socioeconomic and biodiversity data, indicating where considerations related to the LIPI might be included.

4.4 Conclusion

Small-scale fishers across the globe are facing imminent threats and challenges to their livelihoods. Whilst MPAs offer the potential to support fisheries production, a failure to recognise the varying levels of vulnerability of many small-scale fishers means that well-meaning efforts to conserve resources can adversely impact the most vulnerable fishers in unintentional ways (Bennett and Dearden 2014). In this study, we developed a systematic and spatially explicit method to identify those individuals most vulnerable to being negatively impacted by no-take MPAs through an index that represents individual-level vulnerability to MPA restrictions. When used alongside ecological and commercial fishing data, the LIPI can support planners in designing local-scale MPAs that maximise positive impact on biodiversity, and minimise adverse impacts on the most vulnerable fishers in a community.

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Conflict of Interest

The work is all original research carried out by the authors, and all authors agree with the contents of the manuscript and its submission to *Biological Conservation*. No part of the research has been published in any form elsewhere, unless it is fully acknowledged in the manuscript. All sources of funding are acknowledged in the manuscript. The manuscript is not being considered for publication elsewhere.

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4) Marine Science Department, Myeik University, Myeik, Myanmar.

Supplementary Material 1. Survey and participatory mapping exercise.

Interviewer: Date:

Location: Survey #:

Hello, my name is ___, student/teacher from ___. I am here today to find out how people in ___village interact with the ocean. We hope to learn more about your fishing activities. We also hope to learn about your thoughts about sharks.

The interview should take around 30 minutes to complete. Your answers are completely confidential – we will not tell anyone else your answers. The information you provide will be used to guide our research – we will not share the information with anyone. Your participation is voluntary and you can stop the interview at any time. Please tell us if you do not want to answer a question, or if you do not understand the question. Are you happy to go ahead?

Before we start, I have a couple of questions:

1. Do you currently live in this village? Yes No
2. Is fishing one of your activities? Yes No

Only conduct the survey if the respondent answers **'Yes'** to both questions.

Introduction

I would like to start by asking you some questions to learn more about you and your household.

Age: Gender:

Q1: Where are you originally from? (Circle)

This village

Other village in Myeik Archipelago (Specify)

Mainland Myanmar (Specify)

Outside of Myanmar (Specify)

Q2: How long have you lived in this village?

___ all my life OR _____ years

Q3: Which ethnic group do you identify with? (Mark X)

Karen	Moken	Burmese	Other (Specify)

Q4: What grade were you in when you finished school? _____

Q5: Number of people in household?

Working adults _____ Non-working adults _____children_____

Q6: Now I'd like to learn about the activities that you and the members of your household engage in to bring food and money into your household. Let's start with your activities and then we'll talk about the other members of your household.

Q6.1: What activities do you do to bring food and money into your household?

Q6.2.: What activities do other members of your household do to bring food and money into the household?

	*Activity. Indicate * for respondent*	*Rank*
1		
2		
3		
4		
5		

Q6.3: Please rank the top three most important activities for your household. Start with the most important first.

Section 1: Fishing Characteristics

Now I'd like to ask you some questions to learn about your fishing activities. (Show map) This is a map of the area. Before we start, I just want to confirm that you can orient yourself on this map. This is the island we are on, and Myeik is in this direction (*Interviewer: point in the direction of Myeik relative to the map*).

Please point out the location of this village.
Please point out the location of the neighbouring village
Please point out the location of…

Q7.1: Now, can you please use this **black marker** to draw a shape around the boundaries of your 3 main fishing areas – the 3 areas where you go fishing the most. *(Interviewer labels each shape by writing a letter next to it: A, B, C).*

Q7.2: Which of these 3 areas do you fish at the most? *(Interviewer marks an X on the map)*

Q8: Now I'd like to ask some questions about each of these 3 fishing areas. (*Interviewer: start with the area marked 'A', then move on to 'B', then 'C').*

Site	Question							
	What is the main reason you fish here?	What months of the year do you fish here?	During these months, how often do you go fishing here?	How long does it take you to get here?	What gears do you use when you go fishing here?	What do you catch here? (*use fish ID guide)*		*(If identified to species):* Are most of these larger or smaller than the minimum length at maturity? (*refer to shark ID guide)*
						Photo number	**Local Name**	

(Interviewer: determine which column/question to refer to next, based on whether the respondent)…..

Has only reported catching ***sharks***	*Has only reported catching* ***rays***	*Has reported catching* ***both sharks and rays***	***Hasn't reported catching sharks or rays***
Q9: Do you ever catch rays when you go fishing? Yes (*Go to* ***Q11****)* No (*Go to* ***Q12)***	**Q9: Do you ever catch sharks when you go fishing?** Yes (*Go to* ***Q11)*** No (*Go to* ***Q12)***	*Go to* ***Q11***	**Q9: Do you ever catch sharks or rays when you go fishing?** Yes (*Go to* ***Q11)*** No (*Go to* ***Q12)***

Q11: You mentioned that you have caught sharks and/or rays while fishing. I would like to learn more about the sharks and/or rays that you catch. I am interested in what you catch on purpose, and also what you may catch by accident.

Site	Question						
	What sharks/rays have you caught here? ***(use shark/ray ID guide)***		**Are these caught on purpose or by accident? (I/A)**	**How many of this type have you caught at this site in the past year?**	**What do you do with it once you've caught it? (release/sell/eat)**	***If respondent says they release them:*** **Why do you release them?**	***If the respondent said they sell them:*** **Where are the buyers located?**
	Photo number	**Local name**					

How much of your yearly household income comes from selling shark/ray products?
None / Less than half / about half / more than half / all

Can you get more or less money for shark products compared to 5 years ago?
Less / same / more /don't know

Q12.1: Do you ever see other people catching sharks or rays? *(Circle)*

No Only Sharks Only rays Both

If 'No': Skip to ***Q13****.*

If they respond 'Only Sharks', 'Only rays', or ' Both':
Q12.2: Can you please use this red marker to draw a shape around the main areas where you see other boats catching sharks or rays? *(Interviewer writes letter a, b, c inside for further annotation)*

Site	**What months of the year do you see boats catching sharks/rays?**	**What is the level of targeted shark fishing at this site?** (*low/medium/high)*	**Where are these fishers from?**	**Do you know what types of sharks/rays are caught? *(Refer to shark/ray guide)***		**Are these caught on purpose or by accident?**
				Photo number	**Local name**	
		Low ____ Medium ____ High ____				
		Low ____ Medium ____ High ____				
		Low ____ Medium ____ High ____				
		Low ____ Medium ____ High ____				
		Low ____ Medium ____ High ____				

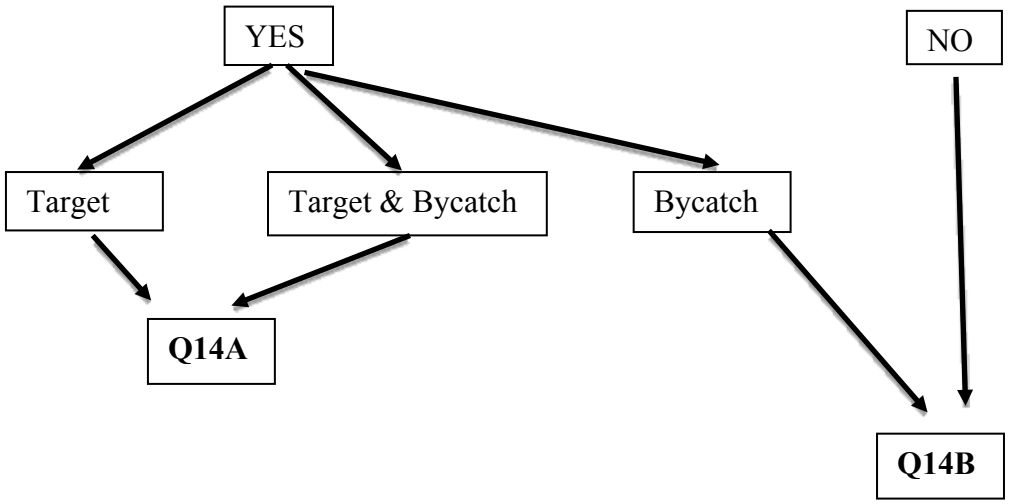
Q13: Are there any other areas we haven't talked about yet, where sharks and rays are known to occur? These areas may be either inside of your main fishing areas. Can you please use this blue marker to draw a shape around these areas. ***(Interviewer annotates with numbers – 1,2,3 etc.)***

(Interviewer: If the respondent does not know of any other areas where sharks and or rays occur, skip to Question 16)

Site	**Are there sharks or rays found here, or both?** Sharks / rays / both	**Do you know what species?**	
		Photo number	**Local name**

As I mentioned at the beginning of this interview, we are interested in learning more about your thoughts about sharks. So, for the rest of the interview I will be focusing on sharks.

*Interviewer: Has the respondent ever caught **sharks**?*



Q14A: For those who have targeted sharks	
Question	Response
Why do you target sharks? List up to two reasons.	1. 2.
How do you think other fishers in your village feel about you targeting sharks? Why do they feel this way?	Approve / disapprove / don't care / I don't know
How would you feel about other fishers in your village targeting sharks? Why would you feel this way?	approve / disapprove / wouldn't care / I don't know

Q14B: For those who have <u>NOT</u> targeted sharks	
Question	Response
Why don't you target sharks? List up to two reasons.	1. 2.
How do you think other fishers in your village would feel about you targeting sharks? Why would they feel this way?	They would approve / they would disapprove / they wouldn't care / I don't know
How would you feel about other fishers in your village targeting sharks? Why would you feel this way?	I would approve / I would disapprove / I wouldn't care / I don't know

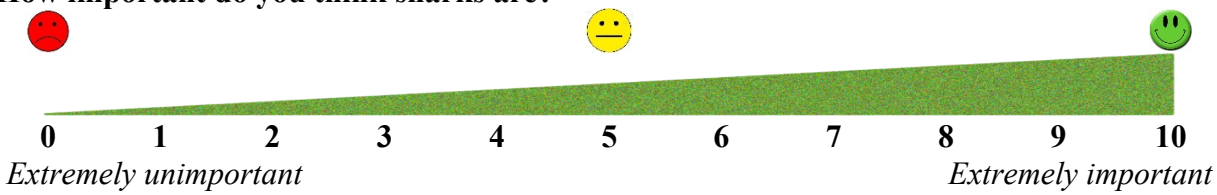
Section 2: Sharks and perceptions of the environment

Now I'd like to learn more about your thoughts on sharks.

Q15.1: In your opinion, are there more or less sharks than there were 5 years ago?
a lot more / a few more / same / a few less / a lot less / don't know

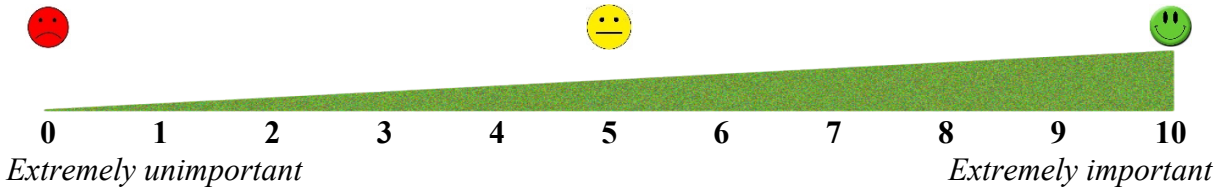
Q15.2: Why do you think this is?

Q16.1: How important do you think sharks are?



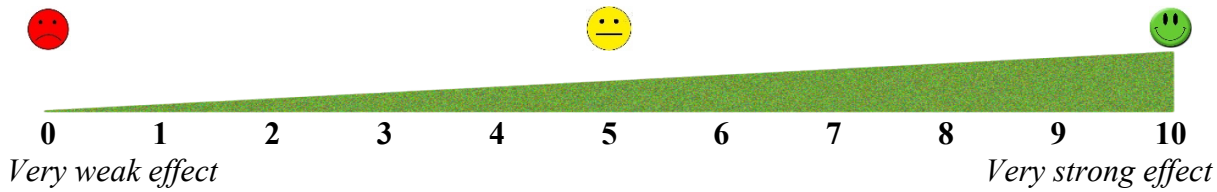
Q16.2: Why?

Q17.1: How important do others in your village think sharks are?



Q17.2: Why?

Q18: How much of an effect do you think shark fishing has on shark populations?



Section 3: Perceived Compliance

Q19: In your opinion, what is the level of targeted shark fishing by people *in this village*?
There is no shark fishing / very low / low / medium / high / very high

Q20: In your opinion, what is the level of targeted shark fishing *in the Myeik Archipelago*?
There is no shark fishing / very low / low / medium / high / very high

Q21: In your opinion, what are the two biggest reasons why people in the Myeik Archipelago would target sharks? List the most important reason first.

1.

2.

Q22: In your opinion, what are the two biggest reasons why people in the Myeik Archipelago would NOT target sharks? List the most important reason first.

1.

2.

Q23: Do you think that sharks are in need of greater protection from fishing? Yes No

Q23.2: Why/why not?

Section 4: Legislation and Compliance

Q24: Are you aware of any rules or laws regarding fishing for sharks?

Yes No

STOP:
*If the respondent has replied 'No', **skip to Section 5**.*

Q25: What rules or laws are you aware of regarding fishing for sharks?

Rule/law 1._____
Rule/law 2._____
Rule/law 3._____

		Rule/law		
		1	2	3
Q26	How did you learn about the rule/law?			
Q27	Who is responsible for enforcing the rule/law?			

(Interviewer: reassure the respondent that we are getting close to the end of the survey)

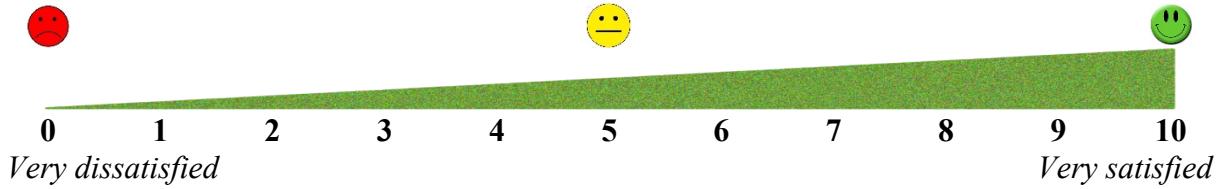
Q28: For the rule(s) you mentioned, please tell us how much you agree or disagree with the following statements. *(If they have listed more than one rule):* I'm going to start with the first rule you mentioned: (*rule/law 1 from above)*

Question	Rule/law		
	1.	**2.**	**3.**
People are well informed about the rule	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**
Who should be responsible for sharing information about this rule?			
I support the rule *Why do you feel this way*?	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**
The rule has been effective for protecting sharks	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**
I was involved in the decision-making process that led to the rule	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**10 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**10 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**
Enforcement of the rule in my area needs to be improved *If response is above 5*: How could it be improved?	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**
I trust that the people enforcing the rules will do their job effectively	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**	**0 1 2 3 4 5 6 7 8 9 10** **strongly disagree** **strongly agree**

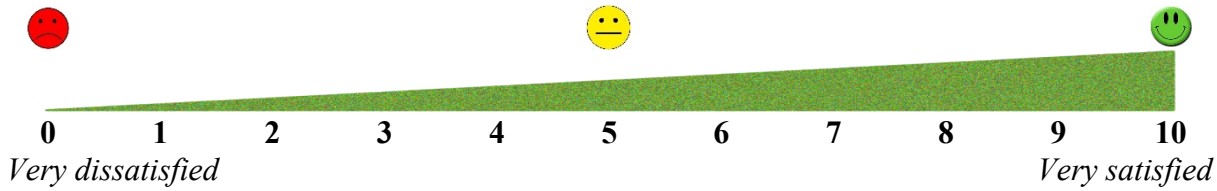
Section 5: Satisfaction with fishing

Now I have some questions about your overall quality of life.

Q29: How satisfied are you with your quality of life?



Q30.1: How satisfied are you with having fishing as one of your activities?



Q30.2: Why do you feel this way?

Q31.1: Would you still be a fisherman if you had your life to live over? Yes No

If 'No':

Q31.3 Is there anything that you would prefer to be doing?

Section 6: To be completed with participant or through viewer observation

Q32: Please circle the relevant box.

Electricity

I own my own generator	I share a generator with another household	I do not have access to any electricity

Roof material

Thatch	Metal	Tile	Other (Specify)

Floor material

Dirt/soil	Bamboo/palm	Plank Wood	Cement	Finished (tiles, etc.)

Wall material

Bamboo/ thatch	Wood (plank)	Stone block	metal	Cement	Other

Transport

Boat Y / N *If Y:* With motor? Y / N	Other vehicle: Please list: _____ Type:

Q33: Finally, if we come back in the future, would you mind if we asked you more questions related to this project?

Yes No

(Interviewer: If yes, ask for name, contact details (address, mobile) and cross - reference with survey number in notebook)

Name:

Contact details:

<u>Thanks for participating!!</u>

END

Supplementary Material 2.. Rotated Component Matrix for Material Style of Life. Highlighted in bold are the factor loadings greater than 0.4 were retained for interpretation in accordance with Fornell and Larcker (1981).

	Rescaled Component 1	Rescaled Component 2
Generator ownership	**.900**	
No electricity	**-.881**	
Roof material (metal)	**.592**	.533
Boat ownership	**.425**	
Wall material (wood)		.901
Wall material (thatch)		-.867

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Supplementary Material 3. Sensitivity analysis for socioeconomic factors that contribute to the Livelihood Impact Potential Index.

Factor combination	Number	Combined mean	Standard Deviation
Combined score (all factors)	**80**	**0.36**	**0.15**
LIPI with 10% increase in age	80	0.38	0.15
LIPI with 10% increase in education	80	0.37	0.15
LIPI with 10% increase in MSL	80	0.37	0.15
LIPI with 10% increase in dependence on marine resources	80	0.37	0.15