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Food supply depends on seagrass meadows in the coral triangle

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Abstract
The tropical seascape provides food and livelihoods to hundreds of millions of people, but the support of key habitats to this supply remains ill appreciated. For fisheries and conservation management actions to help promote resilient ecosystems, sustainable livelihoods, and food supply, knowledge is required about the habitats that help support fisheries productivity and the consequences of this for food security. This paper provides an interdisciplinary case study from the coral triangle of how seagrass meadows provide support for fisheries and local food security. We apply a triangulated approach that utilizes ecological, fisheries and market data combined with over 250 household interviews. Our research demonstrates that seagrass associated fauna in a coral triangle marine protected area support local food supply contributing at least 50% of the fish based food. This formed between 54% and 99% of daily protein intake in the area. Fishery catch was found to significantly vary with respect to village ($p < 0.01$) with habitat configuration a probable driver. Juvenile fish comprised 26% of the fishery catch and gear type significantly influenced this proportion (<0.05). Limited sustainability of fishery practices (high juvenile catch and a 51% decline in CPUE for the biggest fishery) and poor habitat management mean the security of this food supply has the potential to be undermined in the long-term. Findings of this study have implications for the management and assessment of fisheries throughout the tropical seascape. Our study provides an exemplar for why natural resource management should move beyond biodiversity and consider how conservation and local food security are interlinked processes that are not mutually exclusive. Seagrass meadows are under sustained threat worldwide, this study provides evidence of the need to conserve these not just to protect biodiversity but to protect food security.

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Keywords: coral reefs, climate change, fisheries, sustainability, seagrass meadows, food security

1. Introduction

In the tropics, dependence on seafood is high (Donner and Potere 2007) but tropical marine ecosystems are degrading rapidly (Waycott *et al* 2009, Burke *et al* 2011, Giri *et al* 2011) and their fisheries resources are also in free fall due to chronic Malthusian over fishing (Pauly 1998, McClanahan *et al* 2008).

Reasons for the decline of tropical marine ecosystems are multiple, and management rarely takes a fisheries sustainability approach, with marine protected area (MPA) creation the most common course of action (Sale 2008). MPA's often fail to consider the needs of local livelihoods, creating a mismatch between conservation policy and that for local food security (Rice and Garcia 2011, Salomon *et al* 2011).

The abundance of small-scale fisheries throughout the tropics means that fisheries management needs to identify socially acceptable and locally implementable controls on marine resource use (Cinner *et al* 2013, Cohen *et al* 2013). MPA management needs to include partnerships between communities, civil society and government (Evans *et al* 2011, Gutierrez *et al* 2011) so that management supports conservation at the same time as enhancing local livelihood interests.

Tropical marine ecosystems are an interconnected seascape providing a range of resources to marine organisms throughout their life cycle, from daily foraging of adult fish to residence for extended periods of their juvenile life (Harborne *et al* 2006, 2008, Unsworth *et al* 2008, Nagelkerken 2009). Seagrass meadows are a key component of this seascape forming important readily accessible fishing grounds (de la Torre-Castro and Ronnback 2004, Exton 2010, Unsworth and Cullen 2010), providing trophic subsidy to adjacent fisheries (Heck *et al* 2008, Meyer and Schultz 1985) and critical nursery habitat for species of commercial importance (Beck *et al* 2001, Heck *et al* 2003, Gillanders 2006, Nagelkerken *et al* 2012). Fishing throughout this tropical seascape is a multi-geared operation, with line fishing, gill nets, beach seines, fish traps, spears and trawls all used over different habitats types (McClanahan and Mangi 2004). Traditionally all tropical coastal marine fisheries are described as 'coral reef fisheries'. Such fisheries to some may include seagrass, but poor terminology has led to an ill appreciation for the role of seagrass habitats in supporting fisheries productivity and importantly food supply (Unsworth and Cullen 2010, de la Torre-Castro *et al* 2014, Duarte *et al* 2008).

Understanding food supply, its ecological origin and the resources that support it are critical knowledge components of developing appropriate ecosystem based management actions that can foster enhancement of fisheries resources and improve opportunities for food security. Prohibition or controls of a specific fishing activity in one habitat type will have limited impact if those fish migrate at night into an adjacent habitat where they are readily collected by fishers.

Understanding habitat links to fisheries is critical for the consideration of short-term fisheries management but is also important for understanding the vulnerability of marine systems to climate change and their future resilience, key components of determining levels of food security (Folke 2006, McClanahan *et al* 2009). Given the need to understand the role that different habitat types have in supporting tropical marine fisheries, the limited literature and knowledge on seagrass biodiversity in the Indo-Pacific, and the growing evidence of the role of seagrass meadows in supporting Indo-Pacific marine fisheries, here we provide an interdisciplinary case study from the coral triangle of the role of seagrass meadows in supporting local food security. The aims of this research were to: (1) quantify the contribution of seagrass meadow associated fauna to food supply in a marine park of UNESCO world biosphere status (UNESCO 2014) in the centre of the coral triangle; (2) determine whether this supply of seagrass associated fauna is sustainable and the implications of this for local food security.

2. Materials and methods

2.1. Study site

This study was conducted in the Wakatobi National Park (WNP), Indonesia (see figure 1) between July 2012 and May 2013. The WNP is a UNESCO World Biosphere reserve containing extensive and biodiverse reef, mangrove and seagrass systems that are heavily exploited by fishery activities. The WNP is typical of many large MPAs throughout the Coral Triangle. It is also home to a culturally diverse and rapidly growing local population including significant Bajo 'sea-gypsy' communities who are landless and live on stilted villages within the inter-tidal. The culturally Indonesian communities living on the islands are referred to as the Pulo.

2.2. Food security

Food security is defined as '*the ability of the world to provide healthy and environmentally sustainable diets for all its peoples*' (Godfray *et al* 2010). Investigating it requires developing an understanding of both food supply and the sustainability of that supply. A multi-method, or triangulation was used to determine food supply. This was particularly important given supply chains for fish catch and the supply of food to local people of the WNP do not operate in defined pathways. A multi-method or triangulation approach allowed for strengthened claims of validity in our findings and increased powers of persuasion within associated recommendations as a result of the research (Atkinson *et al* 2003, Ruane 2005, Brewer and Hunter 2006). Triangulation of data was conducted at both the interview level and at the study level. At the interview level, the same information was requested in different ways to triangulate the findings. At the study level, triangulation occurred by examining food supply at the market level and through interviews.

This approach concurrently examined fish habitat usage, fisheries exploitation patterns, fisher folk opinions, household interviews and classified fisheries catch relative to habitat usage in order to develop links between habitat and food supply. To understand the sustainability of supply, data was considered with respect to temporal change and key aspects of sustainable fisheries exploitation.

2.3. Fish species usage of seagrass

To link specific fish species to seagrass habitat use a seagrass fish species database was created (see appendix 1). A species was classified as a seagrass associated species (SAP) if it utilized seagrass during at least some stage of its life cycle (recorded present in a seagrass meadow by at least two separate research studies). This allowed all fish species data (fisheries, household survey and market data) to be classified as being 'directly supported by seagrass' or not. The habitat use of all other remaining species found within the fisheries

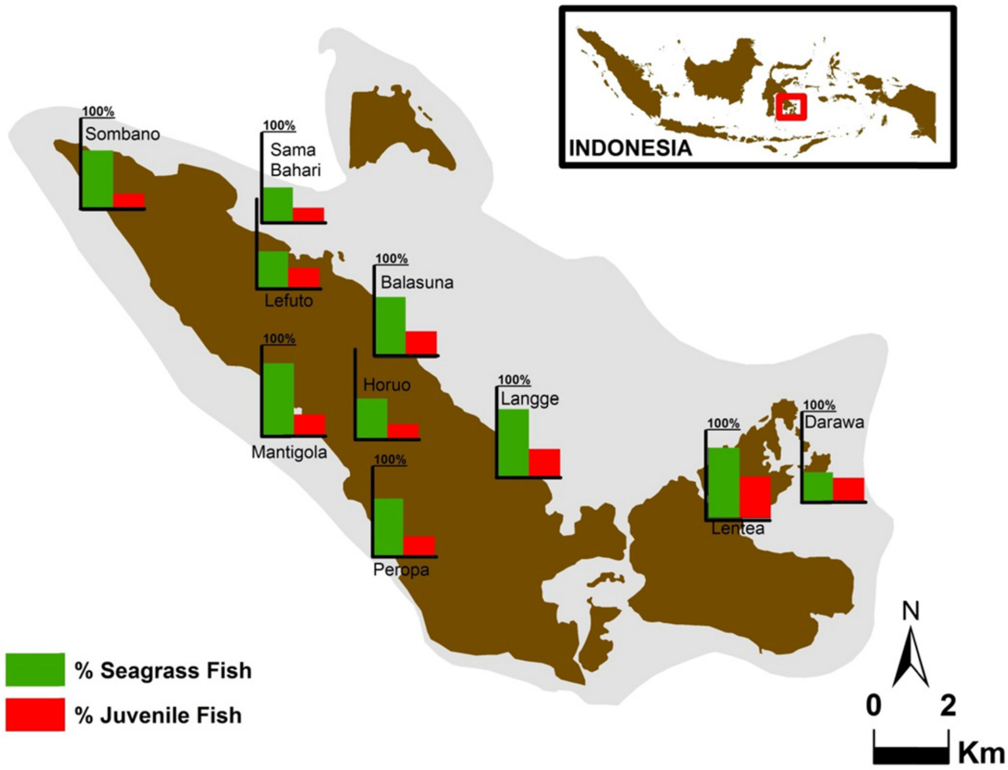

Figure 1. Fishing villages of Kaledupa, Indonesia showing the proportion of local fisheries catch classified as being seagrass associated species (green) or juvenile fish (below size at maturation).

data which were not classified as SAP was determined by fishbase (Froese and Pauly 2013).

2.4. Fisheries catch

Fish catches in ten villages were assessed across the four major gear types (static fyke nets, gill nets, rod and line, fish traps—see Exton 2010). These were a stratified sub-sample of the fishing effort and represent approximately 5% of the catches during that period. Sampling was conducted 2 d per month for three months from January to March 2013 and all fish landed in all gears was assessed. The numbers of fishers (or small groups operating out of one vessel or one item of gear) that were assessed varied between villages (range of 5–21).

All species within each catch were identified (Allen 2000), measured and counted, and the entire weight of the catch determined (to the nearest 0.1 kg). Each fisher was also asked questions about the location, habitat and duration of the fishing activity.

Fish were classified into juveniles and adults based on length at maturity (L_m) being a third of their adult size (Nagelkerken and van der Velde 2002, Dorenbosch *et al* 2005, Unsworth *et al* 2008). Within each fish catch the proportion of fish classified as juvenile (J) was determined as was the proportion of juvenile fish that were considered SAP as either adults or juvenile, these were termed seagrass juveniles (SJs).

Data collected for the fyke net fishery was examined relative to data collected in similar locations in the WNP using the same methodology and published by Exton (2010).

In order to determine the potential impacts of the extraction of species from the wider tropical seascape in terms of long-term sustainability and ecosystem resilience the functional role of the most commonly exploited individual species were defined according to established categories of herbivore (Green and Bellwood 2009). Herbivorous fish have been highlighted for their value of in reducing algal biomass on tropical marine systems, a critical component in helping maintain their overall ecosystem resilience (Mumby and Steneck 2008).

2.5. Fisheries catch data statistics

In order to ascertain the influence of key factors upon fishery catch data was analysed to determine the influence of different factors upon it (habitat fished, gear type, village).

Firstly, from this data we obtained the proportion of fish caught that were classified as seagrass inhabitants, referred to as SI. Secondly, we created a sub category that only contained the number of fish measured, and from this we obtained two key variables: the proportion of fish measured that were classified as juveniles (Js) and the proportion of fish measured that were classified as juveniles of species that inhabit seagrass (SJ). A general linear model (GLM) was developed to further analyse this data (see appendix 2 for detailed GLM design).

2.6. Household surveys

Two hundred fifty four household surveys were carried out across 26 villages (July–October 2012) (Unsworth *et al* 2010). These were conducted to ascertain information of fishing preferences and food consumption. These consisted of 230 *Pulo* (local islanders) interviews and 24 *Bajo* (local 'sea gypsy' people) interviews (see figure 1). Respondents selected their top five choices for fish to eat. All respondents who classed themselves as fishermen were asked additional questions about their fishing activity. Due to the numerous local languages present within the Wakatobi region, not all species names could be translated into Latin. Some species were easily identified to species level, while others corresponded to fish family or order. Each species was then classified as to whether it was a SAP or not.

2.7. Markey surveys

Observational surveys were conducted twice per month at the Kaledupa fish market (July 2012–June 2013). This was to determine the extent of the sale and consumption of the local fisheries catch. Data on fish presence/absence was collected at the point of sale, with species, number in sale and time of day recorded. Surveys were conducted once a month on a daytime high-tide (to maximize fisher landings) for 1 h. Due to the difficulties in recording fish abundance (number in sale), species were examined as present or absent in the markets. Each species was then classified as to whether it was a SAP or not.

3. Results

3.1. SAP

Data within 41 independent studies recorded the presence of 694 species of fish in Indo-Pacific seagrass meadows. 407 of the 694 species were classified as SAP based on at least two separate records for each species (appendix 1). The most commonly recorded species were the Cigar wrasse *Cheilio inermis*, the Thumbprint Emperor *Lethrinus harak*, the White Spotted Spinefoot *Siganus canaliculatus* and the Common silver-biddy *Gerres oyena*.

3.2. Fisheries catch data

A total 296 species of fish were identified in WNP fisheries catches (appendix 3), 106 of these species were classified as SAP (appendix 1). The remaining species were classified according to data within fishbase (Froese and Pauly 2013), 153 of these were of coral reef origin, 33 pelagic and demersal, and six other. Although we categorized 106 WNP species as being SAP, this does not mean that their distribution was restricted to seagrass, merely that they were observed to associate to seagrass as a transient, short term or permanent resident.

Average fish abundance was 64.5 (SD = ± 20.4) per catch and an average of 9.8 (SD = ± 3.6) species were present within each catch (figure 1). Species classed as SAP contributed to 62.4% (SD = ± 14.4) of the total fish caught, this varied with respect to each village (figure 1). All villages had over 50% of fish classified as SAP. Fishermen operated their gear over four different habitats with 67.6% of catches in seagrass, 18% in coral, 13.7% in mixed seagrass and coral and 0.7% in the deep sea.

3.3. Common and functionally important species in fisheries catches

All of the ten most common species found to be present (presence/absence) in an individual fish catch are SAPs and eight out of ten of the most abundant (numerically) species across all catches are SAPs (figure 2). The Thumbprint Emperor *L. harak* was the species most frequently present as it was observed in 31% of all fish catches (figure 3(a)). The Longspine Emperor *Lethrinus genivittatus* (Valenciennes, 1830) was the most numerically abundant species to be caught (figure 3(b)). *Lethrinus spp*. is the most important genus with five and four different species caught in the top species list for presence and abundance respectively. Other species commonly present and recorded in high abundance were the Anchor Tuskfish (*Choerodon anchorago*), the Mottled Spinefoot (*Siganus fuscescens*), the White Spotted Spinefoot (*S. canaliculatus*) and the Common Silver Biddy (*G. oyena*) (figure 2).

Of the most abundant and commonly present species in fish catches many of these are of functional significance to reef systems due to their role as herbivores (Grazers, Browsers and Scrapers) (see appendix 4). These species potentially support the resilience of marine systems within the WNP. Three of the ten most abundant fish caught were Siganids (Rabbitfish), two of which inhabit seagrass. These three species of Siganid are all of value in consuming epilithic and macro algae on nearby reefs increasing reef resilience (Green and Bellwood 2009). Reef scarids of major functional importance were also caught in abundance, as was the functionally important seagrass Parrotfish (*Leptoscarus vaigensis*) (Unsworth *et al* 2007). Due to the decline of the Green Turtle and the Dugong in the region, this seagrass herbivore is one of the few remaining grazers in the seagrass system.

3.4. Juvenile fish in fisheries catches

Twenty six per cent of fish caught were classified as being juvenile, 63% (16.4% of total measured) of these are associated to seagrass (herein referred to as SJs). Juvenile and SJ species contributed to an average of 25.3% (SD = ± 9.4%) and 14.6% (SD = ± 9.1%) per fisheries catch respectively, again this varied with respect to village (figure 1).

Eleven per cent of the total juveniles caught were *Lethrinus lentjan*, 9.3% *L. rubrioperculatus* (Sato, 1978) and 5.7% *L. harak*. Seventy per cent of all *L. lentjan* measured (adult and juvenile) were classed as juvenile, 65% of *L. rubrioperculatus* and 41% of *L. harak* (figure 2).

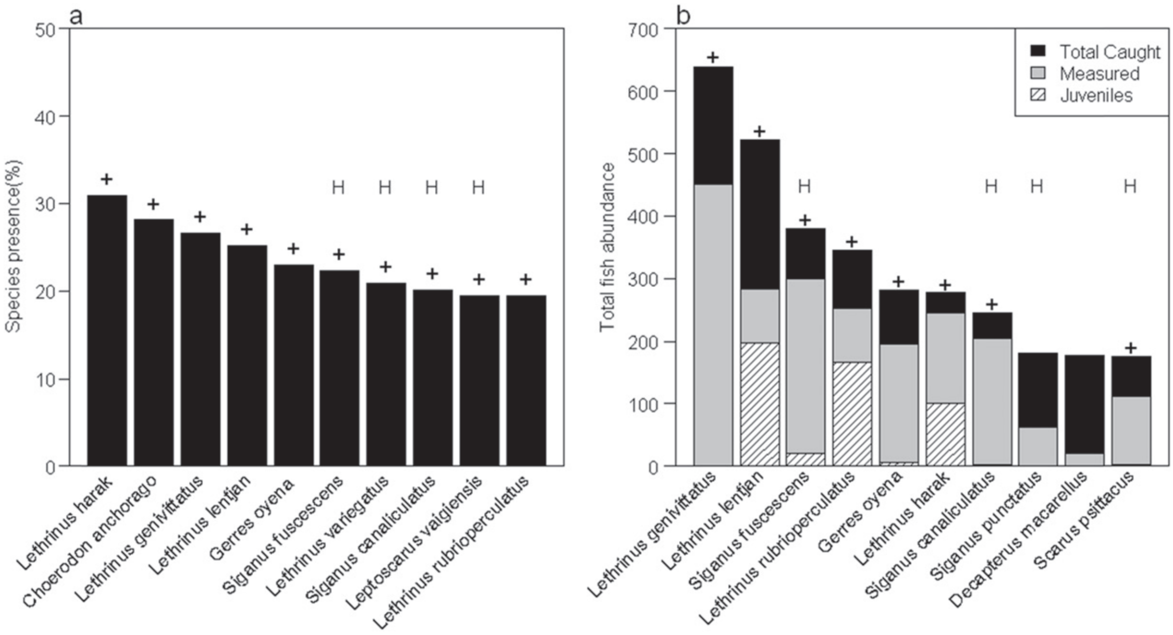

Figure 2. (a) Percentage of the ten species most commonly present, (b) total abundance of the ten most common species recorded within catch landings from Kaledupa. Black: total caught (including measured and juveniles). Grey: total of fish caught that were measured (includes juveniles). Diagonal: number of species measured that are classified as juveniles. + denotes a seagrass inhabitant, H denotes a functionally important herbivore species.

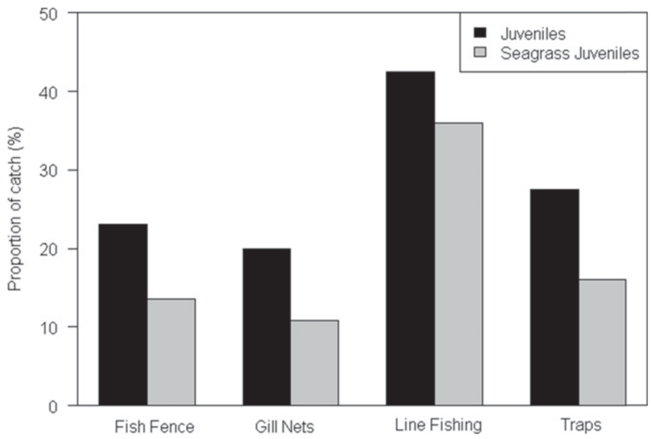

Figure 3. Percentage (%) juveniles (black) and seagrass juveniles (grey) caught using four fishing gears within fisheries catch landings from the Kaledupa.

3.5. Spatial, habitat and gear influence on fisheries catch

We observed significant geographic variation in our outcome measures with both the proportion of fish catch classified as SAP and the proportion of juveniles of seagrass species (SJ) varying significantly between villages ($p = 0.009$, $p = 0.003$ respectively; GLM) (see GLM table appendix 5). Village also significantly influenced the proportion of juveniles of fish that are associated to seagrass (SJ) (average $p = 0.003$, GLM). To explore geographic variation further we added factors to the model that classified villages by their location (North/South, East/West) or by their culture (Bajo 'sea gypsies'/Pulo 'islanders') while retaining village as a random factor in a Linear Mixed Model (LMM). However this generated little of interest with only one significant association ($p = 0.045$; LMM) demonstrating that the proportion of juvenile fish (J) caught was marginally (0.5 percentage points) lower in the East of the island. It is therefore reasonable to conclude that these differences between villages are attributable to the unique configurations of nearby habitat and local conditions for each village rather than being driven by larger scale cultural or regional factors (North/South or East/West).

Gear type also had a significant influence on J and SJ ($p = 0.011$, 0.030 respectively; GLM) with line fishing catching a higher proportion of juveniles in both cases (figure 3).

The habitat type of the fishing activity was found to not significantly influence SI, J or SJ ($p = 0.261$, $p = 0.223$, $p = 0.750$; GLM).

3.6. Favoured fish to eat

A total of 103 fish species were referred to by respondents using local names (Folk Taxonomy), we were only able to translate 70 to a minimum of family level taxonomy (appendix 2).

Of the 252 households 16.1% chose *L. harak* as their most important fish for food. This was consistent across villages. *S. canaliculatus* and/or *S. fuscenscens* were the second most popular taxa (8.7%). These three species are all classified as SAP (figure 5). The families Carangidae, Mullidae, Scaridae and Belonidae were also chosen, but due to translation concerns it is unclear as to which species it is for each family. Two groups were the ninth (2.8%) and tenth (2.4%) choice, which are all oceanic tuna (*Katsuwonus pelamis/*

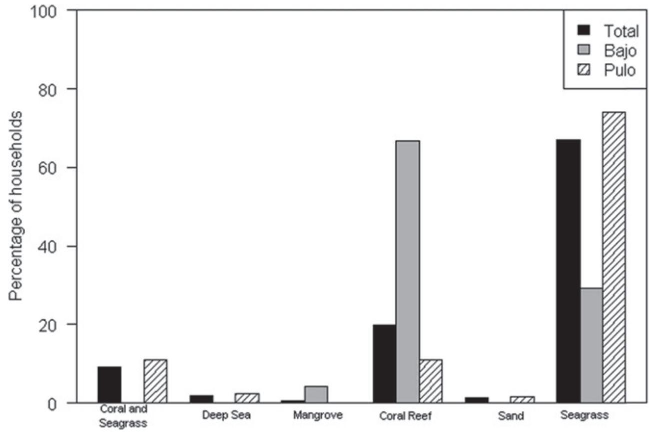

Figure 4. Percentage of households fishing in each identified habitat. A comparison between total surveyed (black, $n = 151$), Bajo (grey, $n = 24$) and Pulo (diagonal, $n = 127$) communities of the Kaledupa.

A*uxis thazard thazard/Euthynnus affinis* and *Auxis rochei rochei*).

3.7. Preferred fishing habitat

Sixty seven per cent of respondents chose 'seagrass' as their preferred fishing habitat (figure 4). A variation occurred between cultures, with the majority (67%) of *Bajo* people preferring to fish at 'Coral Reef', while 74% of *Pulo* favoured 'Seagrass'.

Fish is an important food source for both *Pulo* and *Bajo* villages with 99% and 54% of people eating fish on a daily basis (respectively), the remaining *Bajo* villages stated they ate fish 3–4 d a week (21%) and 5 d a week (25%). The number of times each day fish was eaten was also asked, from this 94% of *Pulo* people surveyed stated they eat fish at every meal, and 71% of *Bajo* said they eat it twice a day and 29% three times a day.

3.8. Temporal change in fish catch

Seventy four per cent of people believed that over the past five years income from fishing had 'gotten worse', with 7% stating that 'fish have gotten smaller', while 12% felt no change had occurred in their income and 7% considered it to be 'better'. However, there is a slight difference in opinion between *Pulo* and *Bajo* villages, 80% of *Pulo* surveyed felt that income has become 'worse', compared to only 42% of *Bajo*. The majority of *Bajo* surveyed believed that their income had not changed, and only 8% thought it had gotten 'better'.

Historical data for fisheries catch of the Sero fishery are contained within the narrative on fisheries in the Wakatobi by Exton (2010). The average Sero catch weight in the present study during 2013 from comparable villages to those described in Exton (2010) were 8.44 kg/fisher/day (SD = ± 1.4). This is a 51% decrease in the average catch weight since 2004 and an 11% decrease since 2007.

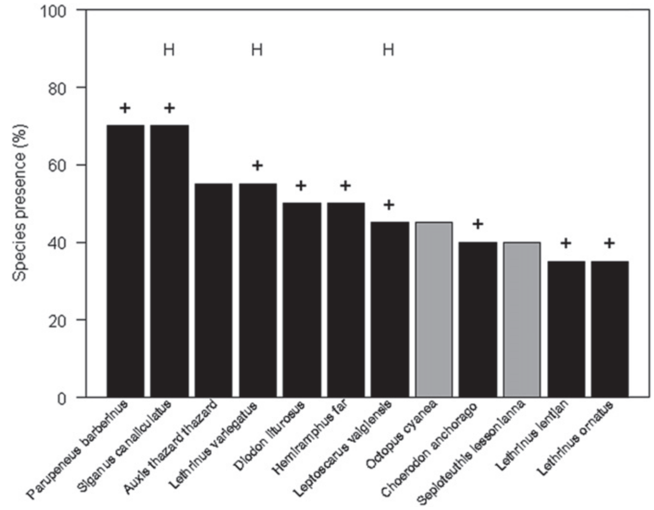

Figure 5. Percentage of the top species present from 20 market samples. Black = finfish; grey = total species (including invertebrates). + denotes a known seagrass resident. H shows a herbivore species.

3.9. Fish species for sale

Market surveys identified 157 taxa being sold, with 144 species classified as finfish. Finfish contributed to the top ten species present in all surveys, with only *Octopus cyanea* and *Sepioteuthis lessonianna* present over 40% of samples (figure 5). From the total finfish data, 41% of species are known SAP, however when examining the most frequent finfish caught (ten species) 90% were classified as SAP (figure 5). The most present taxa were *Parupeneus barberinus* and *S. canaliculatus* occurring in 70% of all 20 samples. These are both SAP.

4. Discussion

Ecosystem conservation that targets the support of fisheries productivity and food security requires a clear understanding of the habitats that underpin them. Here we provide a novel examination of how a multi-species and multi-gear fishery in the tropics is supported by the productivity of seagrass meadows (see figure 6). The site of the present study is typical of coastal and island locations throughout the tropics, where human communities commonly live in close proximity to abundant seagrass meadows that form part of a wider coastal seascape. This suggests the findings of this study require consideration with respect to fisheries management strategies throughout the tropics, particularly within the Indo-Pacific.

We present interdisciplinary evidence that seagrass meadows at the centre of the Coral Triangle support at least 50% of the fish based food supply that accounts for between 54% and 99% of daily protein intake in the area. Given that 68% of fishing activity occurs within seagrass meadows and not on coral reefs as is widely assumed to be the case within many tropical fisheries (Unsworth and Cullen 2010), our study illustrates that making assumptions about where fishing

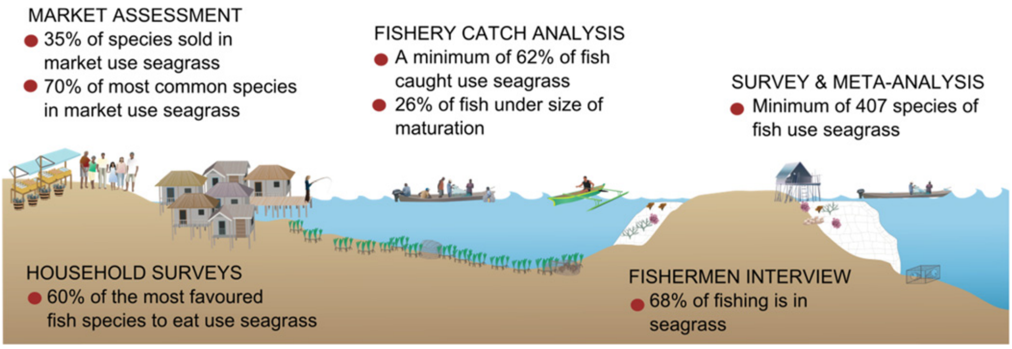

Figure 6. Triangulation of multiple and inter-disciplinary data sources reveals a strong link between fisheries exploitation and food supply to seagrass meadows. Data sources also reveal patterns of unsustainable fishing practices putting local food security at risk.

activity occurs and the biological production supporting fishers can lead to inappropriate management actions being taken.

Marine conservationists have recently begun to re-orientate their analyses towards an emphasis on food security, but are doing so without adequate attention to what food security is, or how fish contribute to it (Foale *et al* 2013). Here we provide evidence that seagrass meadows can form an important habitat to support a major source of food supply. This case study finds seagrass associated fish providing the majority of the fish catch. Although an unknown proportion of the fish caught in the present study is exported from the study site, there is clear evidence that it is consumed and favoured locally and provides a key protein supply. It is however important to note that our fishery surveys are constrained to one season and therefore this role of seagrass may change temporally.

Seagrass meadows, due to their shallow and near-shore distribution provide easy access for all types of fishers (de la Torre-Castro and Ronnback 2004, de la Torre-Castro *et al* 2014), including basic subsistence fishers using only line fishing and canoes. For communities of limited financial means this access can be critical for their long-term wellbeing (Cullen-Unsworth *et al* 2014). The potential of these fisheries resources associated to seagrass meadows to support food security should not be underestimated due to the limited range of alternative food supplies available.

Understanding food security is about determining long-term sustainability of supply as well as availability (Lawrence *et al* 2010). The present study provides evidence of seagrass associated fish in the WNP potentially being unsustainable in the long-term. Declining catches (catches relative to historic data and local opinion) and unsustainable fishing practice (high juvenile catch) indicate that fisheries in the WNP are in decline. These catches also contain numerous herbivorous species of key importance to maintaining resilience of the local marine seascape (Mumby 2006, Mumby *et al* 2007).

The sustainability of supply also requires healthy and productive habitats in support and therefore key species that support resilience of the seascape are a key component of this.

Seagrass meadows are just one of a number of coastal habitats that support fish productivity in the Indo-Pacific, but in the WNP this support generates a significant proportion of fish catch and these habitats are locally under threat. Seagrass in the WNP is threatened by a range of issues common throughout the Indo-Pacific region (Kirkman and Kirkman 2002, Coles *et al* 2011). This puts the sustainability of associated fauna at risk indicating the need to put these habitats on the conservation agenda. As is the case throughout the region, marine conservation in the WNP focuses on reef systems due to issues of limited biological knowledge about the seagrass systems and a perceived lack of charisma provided by seagrass habitats (Duarte *et al* 2008).

Many of the fish defined in our study as being SAP also utilize other habitats often as a function of diel or lunar cycles and for different periods of their life-cycle (Nagelkerken 2009). Although we know many of the general life history trends of some abundant species in the Indo-Pacific seascape, the literature does not contain species specific habitat level life history information for the majority of species observed and consumed as a food source in the Coral Triangle. This is in contrast to our understanding of many coastal fish species in other parts of the world (Beck *et al* 2001, Heck *et al* 2003). Being able to at least link species by an association to an individual habitat (in this case seagrass) is therefore of benefit in terms of the management of these tropical seascapes. This is important given that fishers operate across all habitat types, often in response to the variability in local conditions.

To manage these coastal seascapes an emphasis needs to be placed on management that can truly be considered to be ‘ecosystem-based’, ensuring ecosystem integrity of all habitats and the long-term provision of ecosystem services such as food security. Our research clearly demonstrates that such management needs to consider how and where fishers fish, and their local fishing preferences and habitat knowledge.

Seagrass meadows can provide a major source of habitat for fish of subsistence and commercial value. This has wide implications for how food supply is made secure in the long-term. Seagrass meadows are under sustained threat from a range of impacts worldwide, this study provides evidence of the need to conserve these not just to protect biodiversity but to protect food security.

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