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The total economic value of small-scale fisheries with a characterization of post-landing trends: An application in Madagascar with global relevance

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ABSTRACT

Small-scale fisheries make key contributions to food security, sustainable livelihoods and poverty reduction, yet to date the economic value of small-scale fisheries has been poorly quantified. In this study, we take a novel approach by characterizing post-landing trends of small-scale fisheries resources and estimating their total economic value, including both commercial and subsistence values, in a remote rural region in Madagascar. We construct annual landings and characterize gear and habitat use, post-landing trends, fishing revenue, total market value, costs and net income, profitability, employment and dependence on small-scale fisheries. Our results show that the small-scale fisheries sector employs 87% of the adult population, generates an average of 82% of all household income, and provides the sole protein source in 99% of all household meals with protein. In 2010 an estimated 5524 metric tons (t) of fish and invertebrates were extracted annually by small-scale fishers in the region, primarily from coral reef ecosystems, of which 83% was sold commercially, generating fishing revenues of nearly $6.0 million (PPP, 2010). When accounting for subsistence catch, total annual landings had an estimated value of $6.9 million (PPP, 2010). Our results demonstrate the importance of small-scale fisheries for food security, livelihoods, and wealth generation for coastal communities, and highlight the need for long-term management strategies that aim to enhance their ecological and economic sustainability. Our findings should catalyze national and regional policy makers to re-examine existing fisheries policies that neglect this sector, and spur researchers to better quantify small-scale fisheries globally.

1. Introduction

Recent research and policy have increasingly recognized the importance of small-scale fisheries in terms of wealth generation, poverty alleviation and food security (Allison and Ellis, 2001; Satia and Staples, 2003; FAO, 2005; Béné et al., 2007; Garcia and Rosenberg, 2010). Small-scale fisheries are generally defined by a minimal amount of capital, low-level technologies and household-unit entities (FAO Glossary: http://www.fao.org/fishery/topic/14753/en). Over 90% of people employed globally in capture fisheries and related activities can be classified as small-scale (World Bank/FAO/WorldFish Center, 2010), and when accounting for those participating in occasional or seasonal fishing activities and indirectly dependent on the small-scale sector, small-scale fisheries support the livelihoods and well-being of over five hundred million people worldwide (Béné et al., 2007; FAO, 2012a). Indeed, small-scale fisheries resources are an important source of income and subsistence in many parts of the world, particularly in developing countries where millions of poor people live near the coast and nearly all (97%) of the world's fishers reside (Béné et al., 2007; Pomeroy and Andrew, 2011). Small-scale fisheries can make substantial contributions to food security and poverty alleviation by providing a crucial source of dietary protein (Kent, 1998; Van der Elst et al., 2005; Bell et al., 2009; FAO, 2012b), and, perhaps more importantly, by supporting production and marketing activities which can generate revenues (FAO, 2005).

With effective management, small-scale fisheries can contribute to sustainable livelihoods (Andrew et al., 2007). However,

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small-scale fisheries are typically characterized by remote landing sites and sporadic, decentralized post-harvest and marketing activities that hinder efforts to collect data illustrating their scope, impact, importance and economic value (Salas et al., 2007). This substantial lack of data causes fisheries policies across the globe to neglect small-scale fisheries, and generally hampers efforts to ensure their long-term ecological sustainability and resilience. Moreover, because the contribution of small-scale fisheries to local, national and regional economies is often poorly quantified, they are habitually overlooked at the national policy level (Andrew et al., 2007; World Bank/FAO/WorldFish Center, 2010; Mills et al., 2011). In effect, small-scale fishers, who are typically already disadvantaged by their socioeconomic, political, cultural and physical remoteness, are often further marginalized by national fisheries policies that typically favor large-scale industrialized fishing sectors (Pauly, 1997).

Meanwhile, marine fisheries are facing increasing pressure on a global scale from widespread overfishing (Jackson et al., 2001), habitat destruction (Diaz and Rosenberg, 2008), climate change (Hoegh-Guldberg and Bruno, 2010) and other anthropogenic effects (Halpern et al., 2008). These cascading impacts can severely erode the ability of marine and coastal ecosystems to absorb fishing pressure and continue to provide key ecological goods and services, thereby threatening the livelihoods of millions of people who depend on them for subsistence and income. In many developing countries, this situation is exacerbated by weak institutional frameworks and a lack of enforcement capabilities, both of which are necessary to design, implement and support effective fishery resource policies (Andrew et al., 2007; Pomeroy and Andrew, 2011).

The developing country of Madagascar is a prime example of a convergence of these issues surrounding small-scale fisheries. Madagascar is one of the poorest countries in the world, with annual income per capita barely reaching PPP $950 and over 75% of all households living under the poverty threshold (World Bank, 2012a). Chronic political instability and declining economic trends have plagued the country over the past few decades, intensifying poor socioeconomic conditions (World Bank, 2012a). Nationwide, the majority of households rely on the exploitation of natural resources to support their livelihoods (Horning, 2008; Morisset, 2010) and over half of the population lives within 100 km of the coast (WRI, 2003).

As the fourth largest island in the world boasting one of the largest exclusive economic zones in the Indian Ocean, Madagascar's small-scale fisheries sector is highly significant and has potential to both feed people and support livelihoods. This is particularly the case along the west coast where agricultural production is largely infeasible and employment options are limited (Laroche and Ramananarivo, 1995; Le Manach, 2012). However, the region's marine environments are increasingly threatened by climate change and direct anthropogenic impacts, including coral bleaching events, hypersedimentation, population growth and increasing rates of migration to the coast (Harris, 2007, 2011; Maina et al., 2008; Cripps, 2009; Le Manach et al., 2012; Raberinary and Benbow, 2012). Amidst the growing external pressures on the region's natural capital, recent reports have warned that small-scale fisheries and other marine resources in Madagascar are over-exploited (Harris, 2007, 2011; Cripps, 2009; Le Manach et al., 2012; Raberinary and Benbow, 2012). Acknowledging the considerable role of the small-scale fisheries sector in terms of food security and poverty alleviation and its vulnerability to overexploitation, national level decision makers are showing growing interest in including small-scale fisheries in Madagascar's fisheries management plan, presently under revision. Yet, analogous to the lack of data surrounding small-scale fisheries on a global scale, currently little information exists about the specific inputs, outputs and economic value of the country's small-scale fisheries, and data characterizing the sector are needed for policy development (Harris, 2011; Le Manach, 2012).

Globally, some research efforts have collected biological/ecological small-scale fisheries catch statistics (Pauly and Mines, 1982; Craig et al., 1993; Stergiou et al., 1996; Laroche et al., 1997; Hernandez-Garcia et al., 1998; Marquette et al., 2002), and others have reconstructed small-scale fisheries landings to estimate their contribution to GDP (see: http://www.seaaroundus.org/). There have also been a handful of socioeconomic case studies on small-scale fisheries that estimate revenue and income based on total landings (Bailey, 1982; Tzanatos et al., 2006; Battaglia et al., 2010; Teh et al., 2011), but these studies do not analyze post-landing trends. Post-landing distribution patterns of small-scale fisheries resources vary and can consist of selling, sharing, trading and consuming portions of the total catch (Glazier et al., 2012, 2013; Kittinger, 2013; Vaughan and Vitousek, 2013). An analysis of small-scale fisheries' post-landing trends followed by a total economic valuation based on these trends would provide a more thorough examination of the sector's contribution to food security and poverty alleviation, yet we are unaware of any such attempt that currently exists in the literature.

Here, we attempt to fill this crucial data gap. Specifically, we construct annual landings and post-landing trends for all target species groups in a remote locally managed marine area in Madagascar to analyze the sector's total economic value and socioeconomic contribution. We do this by examining catch characteristics (including gear and habitat use), total fishing revenue, total market value, costs to fishers and net income, profitability, employment and local dependence on small-scale fisheries.

To the best of our knowledge this study is the first total economic valuation of a small-scale fisheries sector that includes post-landing trends and determines both commercial and subsistence values. The current study is also the first that we are aware of to provide a comprehensive estimate of the socioeconomic contribution of small-scale fisheries within a locally marine managed area. In the absence of effective institutional marine and coastal management, locally and community managed marine areas have been rapidly proliferating across the Western Indian Ocean (Harris, 2011), the South Pacific (White, 1989; Pomeroy, 1995; Govan, 2009) and all across Oceania (Johannes, 2002), thus broadening the direct applicability of our methods and results.

This study fills a critical knowledge gap concerning small-scale fisheries which is likely to be useful in a variety of settings. Information on the total economic value of the small-scale fisheries sector can directly benefit resource and environmental policy development and management in Madagascar, and is likely to be applicable to other developing countries on a broader scale. Moreover, by providing first-hand information on post-landing trends of small-scale fisheries resources, this study provides crucial information on the food security role of the small-scale fisheries sector and its potential contribution to poverty alleviation, also with global implications.

1.1. Study area

Madagascar lies in the western Indian Ocean to the east of Mozambique, separated from Africa by the 400 km wide Mozambique Channel. Our study site, Velondriake, lies in the arid Toliara province of southwest Madagascar, where twenty-four villages supported by Non-Governmental Organizations and the National Marine Sciences Institute have united to collaboratively manage a complex array of islands, mangroves and coastal ecosystems (Harris, 2011) (see Fig. 1 for a map of the study area). Velondriake, a locally managed marine area, spans more than 1000 km^2

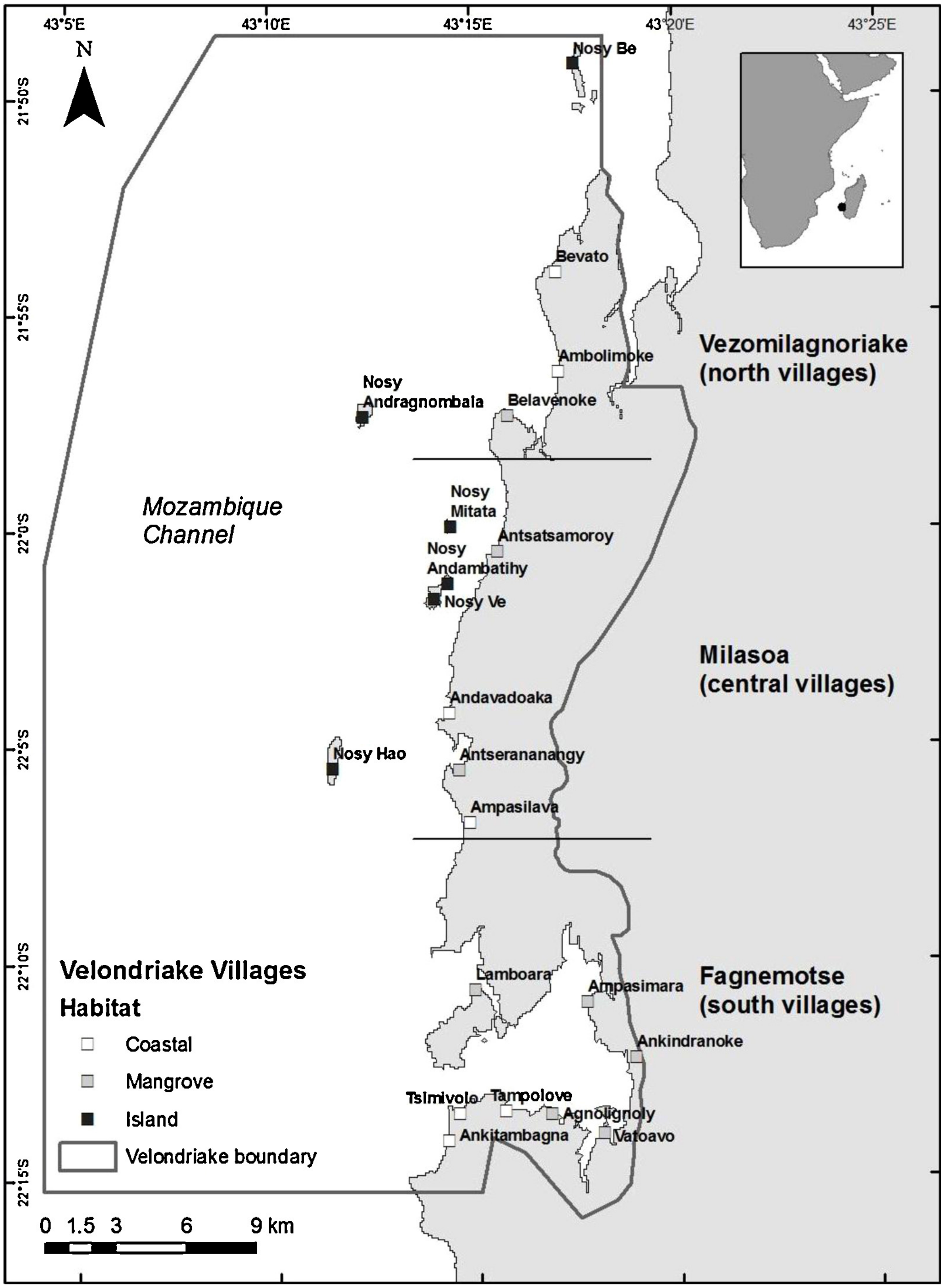

Fig. 1. Map of Velondriake, Southwest Madagascar.

(Harris, 2011) and currently supports a population of over 7500 people. Velondriake, which means "to live with the sea," is home to the Vezo, or "fishing people," whose cultural identity is inextricably tied to the marine environment (Astuti, 1995). The locally managed marine area was established in 2006 and ratified in 2009 in response to concerns over resource depletion; its management plan seeks to empower local communities to manage their coastal and marine resources, support local culture, protect biodiversity, improve livelihoods and promote environmental awareness (Harris, 2007). Following its establishment, a variety of management measures were enacted including a temporary octopus fisheries closure regime, and bans on destructive fishing practices (Andriamalala and Gardner, 2010). Despite these recent achievements, small-scale fisheries in the region still face substantial threats from population growth, increased migration to the coast, environmental degradation and climate change, and concerns have been mounting regarding resource competition with offshore commercial fleets (Harris, 2011; Le Manach et al., 2012).

2. Materials and methods

2.1. Data collection

We collected data using surveys, focus groups, key informant interviews and direct observations. Fieldwork mainly occurred in Velondriake between August and September 2010, though a field-based investigator collected additional information throughout the subsequent two years.

The majority of data comes from a fisher survey (FS), which collected individual-level data on fish and invertebrate extraction, effort, revenues and gear use. The survey design was based on expert advice from local NGO staff and guidelines for collecting baseline fisheries data (Kronen et al., 2007). In remote, data-poor fisheries like this one, surveys asking fishers to recall their catch and effort are often the only practicable method. Self-reported data are less reliable than observed data, especially in this case where we are reconstructing annual estimates by asking fishers to recall their behavior and catch over a relatively long time frame. Fortunately, carefully designed surveys can deliver similar results as creel-type surveys, although they are prone to over-estimation (Kuster et al., 2006). During the interview, a respondent was separated into one of three groups (fisher, gleaner or fisher–gleaner) to account for differences in practice, namely gear and target species. Distinct lines of questioning asked respondents in each group to self-report effort and a catch range (maximum, average and minimum) during different weather conditions and seasons, a method that can reduce bias in interview-derived data (O'Donnell et al., 2012). The survey prompted fishers to report catch across multiple species or species groups, designating the habitat, methods and final use of each (eaten at home, shared, dried, traded, etc.). All surveyors were also fishers, which helped minimize any extraordinary reported catch and effort or misunderstandings. The survey instrument took approximately 60 min to complete.

We randomly sampled age- and gender-representative fishers within each group across three main habitat types (mangroves, coasts and islands) using a non-probability sampling (Henry, 1990). The survey team approached adults (at least 15 years old) on the beach when they came in from fishing or at their homes after they had returned. The sample included fishers and gleaners returning at all times of day, as well as seasonal and occasional fishers and gleaners, and was representative of the sex and age distribution of the population (see Table S.1 in the online supplementary information). The response rate was high (>95%).

Fifty adult respondents were sought in each of three strata determined during focus group meetings (gleaners, fishers in mangrove villages, and fishers in other villages). At about 50 samples, further sampling begins to offer diminishing returns regardless of the variability of the surveyed variable. As our lengthy survey measured a wide array of variables, we judged that 50 respondents per strata provided a balance between efficient use of survey effort and maximal accuracy in estimates obtained. More specifically, our pilot survey of 24 fishers and gleaners returned coefficients of variation from well-sampled variables that ranged from 19.5% to 332%, depending on the variable. Median within-group coefficient of variation across all well-sampled variables was 56%, giving a detectable effect size below 20% within a stratum's 50 respondents or below 12% for the full sample of 150, using standard power analysis assumptions ($\alpha = 0.05$, $\beta = 0.2$).

A separate household survey (HHS) collected data on income sources and demographic characteristics of the population. The design drew on regional guidelines (Malleret-King et al., 2006) and validity recommendations (Fink, 2003). Approximately 35 questions covered a number of topics, only some of which we used, including: age, sex of inhabitants, household income, material style of life, diet and resource exploitation patterns. We alternately interviewed the male or female head of household; the response rate was high (>95%). We sampled forty households in each region when that many households existed (see Table S.2 in the online supplementary information). A region characterizes the village's (and thus household's) geographic location (northern, central or southern part of the study area) and habitat type (coastal, island, mangrove or inland). Eight regions (island north, island central, coastal north, coastal central, coastal south, mangrove north, mangrove central and mangrove south – shown in Fig. 1)[2] enabled extrapolation to non-sampled villages while controlling for factors, such as proximity to market, that might influence key variables, such as income and catch.

We improved reliability by having a local Vezo team undertake all surveys, with standard explanations to start the interviews and a comment period at the conclusion. Locals with extensive training and experience in conducting socio-economic surveys conducted all surveys in Vezo. The survey team leader was fluent in both Vezo and English, and the team's efforts were supervised and results were quality controlled daily by the PI and/or a research assistant. Additional training and piloting of both instruments in two villages occurred prior to roll-out. The HHS' pilot included 42 households, while the FS pilot interviewed 24 fishers; both surveys changed based on the pilot. The pilot results were also the inputs for the power analysis that set the required sample sizes. Quality control procedures constituted double entry in Excel with inconsistency checks.

Focus groups with fishers and gleaners in the main village of Andavadoaka provided data on quantity and cost of gear used, market prices paid for catch, seasons and other information. Key informant interviews with fishers, commercial buyers, local middlemen ("sous collectors"), fish mongers, managers and villagers across Velondriake provided information on such things as: gear costs, frequency and costs of boat repair, etc. Focus group participants and key informants were opportunistically sampled, and snowball sampling identified additional informants. Market surveys and direct observations corroborated information such as market prices of fish and gear. Key informant interviews and market surveys primarily took place within Velondriake, although a limited number occurred outside Velondriake in the region's main port city of Tulear.

2.2. Characterizing small-scale catch

2.2.1. Fisher, gleaner and fisher–gleaner population

Following the work of Teh et al. (2011), we report employment in the small-scale sector as an economic indicator. Here, employment in the small-scale sector is considered to be equivalent to the total estimated number of adult fishers and gleaners in Velondriake. We estimated the total number of adult fishers, gleaners and fisher–gleaners in Velondriake using data from the HHS, where each respondent reported the number of adults in their household who fished, gleaned or fished and gleaned. For villages that were included in the sample ($n = 16$), the number of adult fishers, gleaners and fisher–gleaners per household were averaged across all responses, and these averages were then extrapolated to the total number of households in each respective village to get total fishers, gleaners and fisher–gleaners per village. In order to estimate the number of fishers, gleaners and fisher–gleaners in villages that were not included in the sample ($n = 5$: Nosy Hao (island central), Ankindranoke (mangrove south), Ampasimara (mangrove south), Tsimivolo (coastal south) and Agnolignoly (coastal south)[3]), we used the regional average number of fishers, gleaners and fisher–gleaners per household. The total number of households per village in 2010 was based on estimates obtained from censuses and surveys undertaken in 2006 (Andriamalala, 2008; Epps, 2007),

[2] No households in inland villages were sampled as they were more dependent on farming than fishing, the subject of this study. There were no southern, island villages.

[3] Velondriake's inland villages of Befandefa, Ambalorao and Ankilimalinike, whose livelihood relies more heavily on agriculture, were excluded from this study.

where the 2010 population was estimated assuming a regional population growth of 2.95% (INSTAT, 2012) (see Table S.2 in the online supplementary information).

2.2.2. Constructing annual landings

Main species groups fished by fishers and gleaners in Velondriake were determined in our pilot study and by focus groups, and for fishers included the following categories: finfish, Madagascar round herring, shark, ray, squid, octopus, sea cucumber, lobster, shrimp, crab and turtle. For gleaners the main species groups targeted and caught were octopus, sea cucumber, shellfish, crab, urchin, cowrie shells and bivalves. Fisher–gleaners targeted a variety of the same species being caught by fishers and gleaners. As many different species of finfish were found in Velondriake and many of them had different market prices, fishers were asked to report their catch of finfish partitioned by the following categories in order to facilitate estimating their catch[4]:

(1) *Cheap finfish*: which includes primarily mojarras (Gerreidae), damselfish (Pomacentridae), squirrelfish (Holocentridae), sweepers (Pempheridae), and herring, shads, sardines and menhadens (Clupeidae).
(2) *Average priced finfish (Avg. Finfish)*: which includes primarily sea bass, groupers and fairy basslets (Serranidae), grunts (Haemulidae), snapper (Lutjanidae), goatfish (Mullidae), rabbitfish (Siganidae), needlefish (Belonidae), flatheads (Platycephalidae), spadefish (Ephippidae), barracuda (Sphyraenidae) and mullets (Mugilidae).
(3) *Expensive finfish (Exp. Finfish)*: which includes primarily billfish (Istiophoridae), jacks and pompanos (Carangidae), and mackerel, tuna and bonitos (Scombridae).

Our pilot study, in conjunction with the focus group data, also revealed that average priced finfish as well as cheap finfish, octopus, sea cucumber, shellfish and crab were caught daily, whereas the other species groups identified were caught only occasionally, or opportunistically (see Section 3 for more detail).

Regularly- and occasionally-targeted species groups were handled differently in our survey and analysis. In order to account for seasonality and weather in determining the total number of fisher days for the entire year during which fishers targeted regularly (or 'daily') targeted species groups, respondents were asked to report how many days they typically fish in bad weather and good weather during a one month period in the summer season (3.5 months), the winter season (5 months) and the rainy season (3.5 months). Responses were used to determine the total annual fisher days per individual respondent by averaging reported good weather and bad weather days across the number of months in all seasons.

To estimate the range of a fisher's catch of regularly targeted species, FS respondents were asked to report how many days in a two week period they typically got a good catch, bad catch or normal catch for each respective species group in both good weather and bad weather. These responses were normalized to calculate the probability (as a proportion of 1) of the catch being good, bad or normal on any given fisher day for each individual respondent. Aiming to avoid recollection issues regarding average catch in kilograms per fisher day, while taking into account the varying levels of catch on different days due to weather and other uncertainties, we asked respondents to report their average catch (in kilograms) on a good catch day, a bad catch day and a normal catch day for each regularly caught species groups (such as average priced and cheap finfish or octopus). Thus, each individual respondent's catch per unit effort CPUE for each regularly caught species group rs was:

$$\mathrm{CPUE_{rs}} = [K_{\mathrm{rs,gd}} * \lambda_{\mathrm{rs,gd}}] + [K_{\mathrm{rs,bd}} * \lambda_{\mathrm{rs,bd}}] + [K_{\mathrm{rs},n} * \lambda_{\mathrm{rs},n}]$$

where K = kg/fisher day, gd = good weather, bd = bad weather, n = normal weather and λ = each sampled fisher's normalized chance (probability) of the catch being good, bad or normal on any given fisher day.

For species groups that are only occasionally caught, FS respondents were asked to directly report the average catch of each species group per fisher day in a unit familiar to them, as well as how frequently they caught them. We converted all units to kilograms.[5] Fishers generally reported that most occasionally caught species groups were targeted seasonally or during the spring tide, and we adjusted average annual fisher days for these species groups accordingly. For both regularly and occasionally caught species groups, average annual catch for each respondent was then product of CPUE and fisher days per year.

In addition to each fisher type (fisher, gleaner or fisher–gleaner) exhibiting varying trends in regards to target species, initial observation of the FS statistics discussed above also revealed differences in catch and effort for species groups depending on the respondent's village habitat (island, coastal or mangrove) (see Table S.3 in the online supplementary information for a breakdown of our sample partitioned by habitat and fisher type). Moreover, only a portion of all respondents surveyed reported targeting each species group. Thus, to estimate total annual catch for Velondriake, we extrapolated fisher type- and habitat-specific annual catch means for each species group to the estimated number of each fisher type targeting each species group in each habitat ($\mathrm{EF}_{s,h}$), rather than to the total estimated number of each fisher type. $\mathrm{EF}_{s,h}$ was calculated as:

$$\mathrm{EF}_{s,h} = \left(\frac{\mathrm{SF}_{s,h}}{\mathrm{SF}_h}\right) * \mathrm{TF}_h$$

where $\mathrm{SF}_{s,h}$ is the number of sampled fishers of each type targeting species s in habitat h, and SF_h is the total sampled fishers of each type from habitat h, and TF_h is the total number of fishers of each type in habitat h.[6] Total annual landings of each species group in Velondriake were then simply the sum of its annual landings in each habitat. Total annual landings for Velondriake were then the sum of all species groups' annual landings across all habitats.

To estimate average annual landings *per individual* across all species groups for each type of fisher, Velondriake's total annual landings per fisher type were divided by the total estimated number of each type of fisher (TF), which was then divided by each type of fisher's fisher days per year for daily caught species to estimate their average CPUE across all species groups.

2.2.3. Post-landing trends, fishing revenue and total market value

For all targeted species groups, respondents reported the portion of the total weight of each species they caught that is typically eaten, shared, sold fresh or sold dry. This question enabled us to determine post-landing trends of each species group for each type of fisher. This also allowed us to determine the average fishing revenue derived from each species group, as many species groups

[4] While finfish species grouped here typically had similar market prices per kilogram in Velondriake, the size of the catch also impacted the market price; for example, a large specimen of a species typically considered average priced may have sold for as much as the expensive finfish in some cases.

[5] Conversion ratios were determined in the field using a metric scale. Cowrie shells are an exception, which are reported in pieces in the present study.

[6] Since our sample did not include fisher-gleaners from the coastal habitat (see Table S.3 in the online supplementary information), we interpolated data for this group by applying fisher-gleaner sample means (across all habitats).

have different market prices associated with being sold dry or fresh. Annual fishing revenue[7] for each species group s was:

$$R_s = \mathrm{TL}_s * \alpha_{s,d,f} * P_{s,d,f}$$

where R_s = annual fishing revenue per species group; TL_s = total annual landings of each species group, α_s = percent sold dry d or fresh f; and P_s = the market price of sold dry d or fresh f; and total annual landings TL_s = the sum of all annual landings by the total estimated number of fishers, gleaners and fisher–gleaners targeting the species group in Velondriake. Market prices for each species group were derived from focus groups, market surveys and key informant interviews, and were assumed constant across all of Velondriake for 2010.

Since some landed fish and invertebrates are consumed locally and shared and thus do not contribute to local revenues, we also calculated the total market value of total estimated landings to account for this subsistence catch by attributing the fresh market price to the proportion of the total estimated landings reportedly eaten and shared.

In the online supplementary information tables S.4–S.9, we report a thorough breakdown of catch characteristics, post-landing trends, fishing revenues and total catch values by fisher type and species group. Though all of these statistics were originally calculated by habitat, here, we report Velondriake-wide means M weighted by habitat h for each species group s, calculated as:

$$M_s = \frac{\sum_h M_{s,h} * \mathrm{EF}_{s,h}}{\sum_h \mathrm{EF}_{s,h}}$$

where $M_{s,h}$ is the variable's species group- and habitat-specific mean and $\mathrm{EF}_{s,h}$ is again the estimated number of fishers/gleaners/fisher–gleaners targeting that species in that habitat.

2.2.4. Net income and profitability

Following the work of Teh et al. (2011), profitability was defined as the ratio of annual fishing income to annual fishing revenue. Profitability for each type of fisher was:

$$P = \frac{\mathrm{NI}}{\mathrm{TR}}$$

where NI = net income per year, TR = total fishing revenue per year; P = profitability; and

$$NI = \mathrm{TR} - \mathrm{TC}$$

where TC = total annual costs of fishing. Total annual costs of fishing included the annual cost associated with all gear items being used (including fishing canoes/boats) by all fishers,[8] where the annual cost per gear item g was calculated as:

$$c_g = \frac{p_g}{l_g + r_g},$$

where c = average annual cost of gear item g, p = market price, l = lifespan in years, and r = annual repair costs. Information on the market price of gear items, their lifespan and associated annual repair costs were derived from focus group discussions and key informant interviews, and were found to be relatively standard across fisher type. Information on the quantity of each type of gear item used was reported by respondents in the FS.

2.2.5. Fishing method and habitat utilization

In our FS, all respondents who fish were asked to report what method they use when targeting each species group: net, free dive, line or a combination of these. Thus, we were able to attribute the portion (by weight) of total estimated landings by all those who fish (not including landings by gleaners) in Velondriake to each gear type. All FS respondents also reported what habitat they typically caught each species group in (reef, mangrove, seagrass beds, pelagic waters, mud or miscellaneous/other), which enabled us also calculate the portion of each species (by weight) caught in each habitat. Here, the proportions were derived directly from our sample, i.e., the proportion of the total sum of annual landings by each fisher type surveyed, caught with each method and in each habitat.

2.2.6. Small-scale fisheries dependence

In order to estimate local dependency on the small-scale fisheries sector for income, we employed data from our HHS to determine the proportion of total reported annual income per household in 2010 that is directly generated from fishing and gleaning D as:

$$D = \frac{I_{\mathrm{ssf}}}{\mathrm{TI}}$$

where, I_{ssf} is the total average annual income per household that is generated from small-scale fishing and gleaning, and TI is the total average annual income per household.

2.2.7. Quantifying uncertainty

To account for variability and uncertainty in our estimates, we used standard procedures for propagating error (Taylor, 1982), which enabled us to carry over standard errors and standard deviations through all calculations. We report both for individual estimates in our tables, and report standard errors for all aggregate estimates. When we use the ± symbol, we are referring to standard errors.

All currency results were converted to year 2010 international dollars (PPP), a unit of currency that adjusts local currency for purchasing power. The conversion rate used was 1076 Malagasy Ariary (MGA) per $1 international dollar (World Bank, 2012a).

3. Results

In 2010, the small-scale fisheries sector in Velondriake employed 2756 fishers and gleaners, or 87% of the total estimated adult population. Fishers were predominately men (97% of fishers and 95% of fisher–gleaners), while gleaners were predominantly women (98% of all gleaners). Fishers primarily reported targeting average priced and cheap finfish on a daily basis while only occasionally (or opportunistically) targeting expensive finfish, Madagascar round herring, shark, ray, squid, octopus, sea cucumber, lobster, shrimp, crab and turtle. Gleaners reported targeting octopus, sea cucumber, shellfish and crab daily, while only occasionally catching urchin, cowrie shells and bivalves. When fishing, fisher–gleaners also reported targeting average priced and cheap finfish daily while only targeting expensive finfish occasionally, but did not report targeting shrimp, crab or turtle at all. When gleaning, fisher–gleaners also reported targeting octopus and sea cucumber daily, and sea urchin and cowrie shells occasionally.

Accounting for all fishers, gleaners and fisher–gleaners, our results show that a total of 5524 t of fish and invertebrates were extracted from the Velondriake region in 2010, in addition to 43

[7] Annual fishing revenue statistics, in addition to post-landing trend statistics, were calculated first by fisher type and habitat by applying the same method used to calculate catch statistics. Because the details of this approach are explained in the previous section, we omit them here.

[8] Because gear size and cost were relatively standard, gear costs were not weighted by habitat.

Table 1
Total landings and percentage sold, fishing revenues and total market value for 2010.

Species group	Landings (*t*)	Std. error	% sold	Fishing rev.	Std. error	Total value	Std. error
Cheap finfish	2615	228	0.78	$1667	$122	$2029	$126
Sea cucumber	189	37	1.00	$1562	$280	$1562	$280
Octopus	1009	59	1.00	$889	$52	$891	$52
Avg. priced finfish	974	87	0.80	$786	$54	$964	$56
Mad. R. herring	433	161	0.94	$753	$282	$776	$282
Crab	84	21	1.00	$78	$20	$78	$20
Squid	40	8	0.72	$107	$20	$148	$22
Lobster	4	0	1.00	$31	$4	$31	$4
Exp. finfish	23	6	0.86	$28	$6	$32	$6
Shrimp	22	6	0.88	$25	$5	$27	$5
Shark	21	6	0.89	$12	$3	$13	$3
Bivalve	33	5	0.08	$4	$1	$46	$7
Shellfish	11	2	0.13	$6	$2	$50	$7
Urchin	51	12	0.11	$4	$1	$37	$8
Cowrie shell[a]	43	33	0.02	$4	$0	$187	$145
Ray	16	2	0.32	$2	$0	$7	$0
Turtle	0	0	0.31	$0	$0.1	$0	$0.3
Total:	5524[b]	302	0.83	$5958	$430	$6880	$431

Note: All dollar values are in thousands of PPP, 2010.

[a] Cowrie shells are reported in thousands of pieces.
[b] Plus 43 thousand pieces of cowrie shell.

Table 2
Gear use by total annual landings by all individuals who fish, 2010.

Gear type	Tons ± std. error	Proportion of total catch
Net	3194 ± 248	0.72
Free dive	599 ± 33	0.14
Line	439 ± 28	0.10
Net, free dive and line	176 ± 11	0.04

thousand pieces of cowrie shell (Table 1). Cheap finfish constituted the majority of the catch by weight, followed by octopus and then average priced finfish (Table 1). Gleaning methods were fairly standard, consisting of gathering by hand or with the use of spears on reef flats and seagrass beds. The majority (72%) of annual landings by all those who fish were caught net fishing (Table 2). Fishing habitats consisted of coral reefs, mangroves, seagrass beds, pelagic waters, mud and other miscellaneous habitats; though reef habitats were the most heavily utilized, followed by mangroves (Table 3).

All individuals reported selling 100% of their octopus, sea cucumber, squid and lobster catch and nearly 100% of their Madagascar round herring catch (Table 1). Shellfish, urchin, bivalves, turtle and ray were primarily consumed and shared locally, as was a portion of the total catch of most other species groups (Table 1). Overall, 83% of the total fish and invertebrate catch by all fishers, gleaners and fisher–gleaners in Velondriake was sold (Table 1), while the rest was consumed locally and shared. According to our HHS, locally caught seafood (primarily finfish) constituted nearly all of a household's non-rice protein, being the protein source in 99% of household meals with concentrated protein (beans, eggs and meat were the others).

Turning now to individual catch and effort, fishers had the highest CPUE with a weighted mean of 13.6 ± 0.5 kg per fisher day, while

Table 3
Habitat utilization by total fishing and gleaning annual landings, 2010.

Habitat	Tons ± std. error	Proportion of total catch
Reef	2491 ± 104	0.45
Mangrove and other[a]	1910 ± 139	0.34
Seagrass	593 ± 43	0.11
Misc.	296 ± 77	0.05
Pelagic waters	175 ± 11	0.03
Mud	59 ± 5	0.01

[a] Some species groups were concurrently reported to originate in mangrove habitats as well as other habitats, hence the category 'mangrove and other'.

gleaner's CPUE was 4.7 ± 0.2 kg per fisher day and fisher–gleaner's was 11.3 ± 0.4 kg per fisher day (Table 4). Fishers reported a weighted average of 224 ± 6 total fisher days per year and gleaners reported a weighted average of 118 ± 5 total gleaning days per year (Table 4). Fisher–gleaners reported a weighted average of 235 ± 9 fisher days per year and an additional 120 ± 7 gleaning days per year. Though it is likely that at times fisher–gleaners fished and gleaned on the same day, to account for the annual effort of both fishing and gleaning we added fishing and gleaning days to get a total of 335 ± 10 days per year (Table 4). Average annual landings per individual fisher were approximately 3.1 ± 0.3 t; per gleaner were estimated at 0.5 ± 0.04 t; and per fisher–gleaner at 4.0 ± 0.3 t (Table 4).

Velondriake-wide fishing revenues[9] in 2010 were $5.96 ± $0.4 million, while the local market value of total estimated catch was $6.9 ± $0.4 million[10] (Table 1). Cheap finfish, comprising the largest proportion of Velondriake's total catch by weight, generated the greatest fishing revenues and had the highest market value when accounting for the percentage of the catch that was eaten and shared (Table 1). Despite the fact that sea cucumber comprised a low proportion of Velondriake's total catch by weight, sea cucumber was the second highest fishing revenue-generating target species group in 2010. Velondriake-wide fishing revenues from octopus came in third followed by average priced finfish and then Madagascar round herring, a seasonal species.

Table 5 reports annual fishing revenues, costs, net income and profitability per individual and for the total estimated population of fishers, gleaners and fisher–gleaners in Velondriake for 2010. Individual fisher–gleaners generated the highest net annual income at $3272 ± $288 on average (Table 5). By comparison, individual fishers generated an average of $2429 ± $319 in net annual income, while individual gleaners generated an average of $987 ± $194 in net annual income. To compare annual income to daily income incorporating effort, we calculated average income per fisher day by dividing net annual income by total annual fisher days for each type of fisher.

[9] Here, we refer to gross revenues from fishing and gleaning activities as fishing revenue.
[10] Market value reflects the total landed value of the catch as if the total catch was sold fresh at local market prices.

Table 4
Catch characteristics per individual fisher, gleaner and fisher–gleaner for 2010.

	CPUE (kg/FD)	FD/year	Annual landings (t)	% of catch sold	Income/FD
Fisher	13.6	224	3.1	0.83	$10.85
Std. error	0.5	6	0.3		$1.45
SD	4	31	1.3		$7.30
Gleaner	4.7	118	0.5	0.87	$8.36
Std. error	0.2	5	0.04		$1.69
SD	1.5	24	0.2		$7.05
Fisher–gleaner[a]	11.3	355	4.0	0.83	$9.22
Std. error	0.4	10	0.3		$0.85
SD	2.5	41	1.3		$3.12

[a] To account for the annual effort of both fishing and gleaning, fishing and gleaning days were summed; however, it is likely that at times, fisher–gleaners fish and glean on the same day.

Table 5
Net income and profitability for 2010.

	Per individual			Total	Velondriake total			Avg.
	Rev.	Costs	Net	Pop.	Rev.	Costs	Net	Profitability (%)
Fishers	$2.85	$0.42	$2.43	950	$2704	$396	$2308	0.85
Std. error	$0.32	$0.03	$0.32		$314	$32	$312	
SD	$1.60	$0.07	$1.60					
Gleaners	$1.15	$0.17	$0.99	1334	$1538	$222	$1316	0.86
Std. error	$0.19	$0.02	$0.19		$260	$26	$259	
SD	$0.81	$0.03	$0.81					
Fisher–gleaners	$3.63	$0.36	$3.27	472	$1716	$171	$1544	0.90
Std. error	$0.29	$0.02	$0.29		$136	$11	$136	
SD	$1.04	$0.04	$1.04					
				Total	$5958	$790	$5168	0.87

Note: All dollar values are in thousands of PPP, 2010.

Fishers earned an average $10.85 ± $1.45 per fisher day, gleaners $8.36 ± $1.69 per fisher day and fisher–gleaners $9.22 ± $0.85 per fisher day (Table 4). Accounting for the total estimated population of fishers and gleaners, in 2010 Velondriake's small-scale fisheries sector generated an estimated $5.2 ± $0.4 million in net income (Table 5). Profitability varied little across all fisher types, averaging 0.87 (Table 5).

Lastly, our results indicate that Velondriake's population is highly dependent on small-scale fisheries resources for income, with an average of 82.4% of all household income being directly generated from fishing and gleaning in the small-scale fishing sector in 2010. Additionally, most other reported income generating activities were indirectly dependent on the small-scale fishing sector, for example, income generated by commercial sous collectors and exporters.

For a thorough breakdown of catch characteristics, post-landing trends, fishing revenues, habitat and gear utilization by fisher type and species group, and on costs per type of fisher, please refer to Tables S.4–S.12 in the online supplementary information.

Our estimates are uncertain, particularly for the occasionally targeted species groups where we were faced with small sample sizes and/or large variations around our sample statistics (Tables S.4–S.6). In particular, our sampled fisher–gleaners only rarely reported targeting expensive finfish, shark, ray, lobster and cowrie shells, thus we were unable to derive standard deviations and standard errors (Table S.6 in the online supplementary information). We acknowledge this uncertainty and include all reported targeted species groups for all fisher types in our extrapolation and final aggregate estimates, because for a data-poor fishery, it is an improvement to have even limited data along with a clear understanding of the data's limitations.

4. Discussion and conclusion

Though national policies typically overlook small-scale fisheries due to their assumed relatively minor economic contribution to GDP or export earnings, the sector can have very important implications for the social and economic welfare of fishers (Teh et al., 2011), particularly in small coastal and island villages in developing nations. Here, we found that small-scale fisheries resources and coral reef ecosystems are crucial for supporting the welfare and livelihoods of the local population within southwest Madagascar's Velondriake locally managed marine area. The local small-scale fishing sector employs 87% of the adult population, generates an average of 82% of all household income and is the sole protein source in 99% of all household meals with concentrated protein. In 2010 alone an estimated 5524 t of fish and invertebrates were extracted by small-scale fishers in the region, primarily from coral reef ecosystems, of which 83% was sold generating fishing revenues of nearly $6.0 million (Table 1). When accounting for the portion of the total catch which was shared and consumed locally, total annual landings were estimated to have had a total economic value of $6.9 million.

Though there is some uncertainty associated with our estimates, our results indicate that the small-scale fisheries sector in this small region of Madagascar alone is at least one and a half times as valuable as the annual revenue Madagascar earns from concessioning its waters to EU tuna vessels (Le Manach et al., 2013), and a sixth as valuable as the entire domestic commercial shrimp industry, industries that get substantial policy attention (Le Manach, 2012). National fishery policy's omission of small-scale fisheries is mainly driven by a lack of data, so even a rough estimate of sector's total contribution at a national scale could underscore its importance. Extrapolating our robust, local results in Velondriake to the national scale using qualitative arguments about how the local estimates should be modified to represent regional differences (see 'Extrapolation to National Scale' in the online supplementary information), we find a total national level catch from subsistence and artisanal fishers and gleaners in Madagascar of over 350 thousand tons per year in 2010. This national scale estimate is *highly* uncertain, and should be treated with due skepticism and be updated as more regional-scale data on small-scale fisheries becomes available. However, it does indicate that previous estimates, even Le Manach's (2012) recent estimate of 107 thousand tons per year in 2008 (based on a readjustment of FAO statistics using available data), are likely far too low, speaking to the urgent need for better data and the inclusion of small-scale fisheries in national policy discussions.

The present study found average catches rates per unit of effort (CPUE) (Table 4) for fishers that were slightly higher than other reports from southwest Madagascar (e.g., Laroche et al., 1997; Brenier et al., 2011). This is not surprising as the most commonly cited Malagasy small-scale fisheries CPUE statistic (i.e., Laroche et al., 1997) is 20 years old and exclusively considers finfish catch, whereas we included all finfish and invertebrate catch in computing CPUE. Moreover, our study site is substantially more remote than the areas examined in previous studies (suggesting effort is likely to be less intense). Lastly, it is possible that the CPUE found here may, in part, be a result of management measures supported by the locally managed marine area established in the region, as the present study is the first to report small-scale fisher's CPUE from within one of Madagascar's locally managed marine areas.

Finfish, followed by sea cucumber, had the greatest total market value and generated the greatest fishing revenues (Table 1), despite the fact that octopus has frequently been cited to be the most economically important target species group in the region (Harris, 2007, 2011; Epps, 2007). Though the total estimated octopus extraction by weight was over five times that of sea cucumber, and 100% of the total catch of both species groups were sold, high demand in Asian markets have made sea cucumbers some of the world's most valued marine commodities (Conand, 2008). Indeed, we found sea cucumber's local market price by weight to be almost nine times that of octopus. Still, our results indicate that finfish was the most economically important target species group in the region, though only 78% of the total finfish catch was sold (Table 1). This result substantiates a recent claim that the economic contribution of finfish in Madagascar has been largely undervalued (Le Manach, 2012). As noted by Le Manach (2012), most transactions regarding finfish in Madagascar happen in villages (such as the ones studied here), hiding and grossly underestimating the total contribution of finfish fisheries to GDP, livelihoods and wealth generation. In contrast, octopus and sea cucumber are primarily sold to outside buyers and exported to developed countries at high prices (Le Manach, 2012), providing an influx of cash to the villages and country, driving broader acknowledgment in previous reports. Our findings suggest that Velondriake's management strategies should give further consideration to finfish as well as sea cucumber. Initiatives aiming to increase ecological and economic sustainability of these target species groups would complement current regional octopus fisheries initiatives, and would enhance the contribution of small-scale fisheries to local livelihoods.

Global attention has increasingly focused on the potential contribution of small-scale fisheries to poverty reduction (FAO, 2005; Béné et al., 2007). As one of the poorest countries in the world, the ability of small-scale fisheries to improve poverty is certainly of considerable interest in Madagascar (Le Manach et al., 2012). According to our results, daily per capita income from fishing and gleaning in Velondriake amounts to $2.13[11] in 2010, which is just slightly above the international and national poverty line ($2.00 and $1.30, respectively). This indicates that although fishing and gleaning in the region generates positive profits and has a relatively high average profitability ratio (0.87), the rents accrued from the small-scale fisheries sector are barely sufficient to keep local inhabitants out of poverty. It is clear in this case, however, that small-scale fisheries resources play a significant role in sustaining local livelihoods and preventing households from falling further into poverty, similar to the role small-scale fisheries have been hypothesized to play in the past (Béné et al., 2007) and were recently found to play in Sabah, Malaysia (Teh et al., 2011).

Another key contribution of small-scale fisheries is toward food security (Béné et al., 2007), which is of considerable interest in developing countries and in coastal regions where fish is often a key source of protein (Kent, 1998; Van der Elst et al., 2005; Bell et al., 2009; FAO, 2012b). In Madagascar, small-scale fisheries can play a crucial role in this regard (Harris, 2007, 2011; Rakotonirainy et al., 2011; Le Manach et al., 2012) as the sector makes up the largest component of domestic fisheries catches, accounting for 72% of total landings in the 2000s (Le Manach et al., 2012). Our results indicate that nearly all concentrated protein eaten in our study site was seafood, and over 80% of all household income was derived from small-scale fisheries, the majority of which is used for purchasing staple food, such as rice (Epps, 2007).

Small-scale fisheries can be vital for coastal populations in terms of wealth generation, livelihood sustainability and food security, but these are threatened by widespread overexploitation and looming climate change impacts (Pauly, 1997; Allison et al., 2009; Cheung et al., 2009). The high reliance on small-scale fisheries resources for subsistence and income found here highlights a substantial situation, as Madagascar's west coast, where most small-scale fisheries are located, is currently experiencing high levels of unsustainable fishing and increasing incidental catch rates from nearby shrimp trawlers (Le Manach et al., 2012). Some areas in southwest Madagascar are already experiencing marked declines in finfish size and catch, and if current fishing trends continue, small-scale finfish catches nationally may begin to decline within 10–20 years (Le Manach et al., 2012). In addition, high export prices for sea cucumbers incentivize over-exploitation (Le Manach et al., 2012), and recent reports have warned of serial depletion globally (Anderson et al., 2010) and precarious declines throughout the western Indian Ocean (Muthiga et al., 2010). Madagascar is also ranked amongst other tropical countries with the lowest adaptive capacity and very high vulnerability to climate change and other external shocks (Maina et al., 2008; Cinner et al., 2009; Burke et al., 2011; Harris, 2011). As the region may experience dramatic changes by as early as 2030 (Ateweberhan and McClanahan, 2010), including a potentially substantial redistribution of catch potential (Cheung et al., 2010) coupled with a decrease in marine fish body size (Cheung et al., 2012), adaptive strategies that seek to increase fisheries sustainability and community resilience are urgently needed.

At the national scale, our results suggest an urgent need to improve the institutional capacity of the regulating bodies, and a reorientation of the national fisheries policy toward small-scale fisheries. A recent World Bank study found a hodge-podge of state institutions charged with managing the fisheries sector in Madagascar with overlapping mandates, roles and responsibilities, and poor coordinating mechanisms, capacity and resources for effective enforcement (World Bank, 2012b). The last coherent fisheries policy for the nation expired in 2007, and the legislative framework governing fisheries altogether ignores small-scale fisheries and their supply chains (many of which are export-oriented). As the country reviews its fisheries regulations and embarks on the process of establishing a fisheries management plan, it is imperative that policy incorporates the substantial contribution of small-scale fisheries and that it addresses the threats they face; a recommendation which is generalizable to other regions throughout the world. In our study site as well as globally, small-scale fishers face increasing resource competition from commercial fleets sparked by declining catch (Pauly, 2006; Le Manach et al., 2012). We have shown that small-scale fisheries have substantial economic value,

[11] This statistic applies across Velondriake's total population.

but realize that policy is often driven by a sector's contribution to GDP or export earnings. Therefore, we echo Le Manach et al. (2012) in suggesting that sustaining small-scale fisheries be viewed as a human rights issue and given precedence over export-oriented commercial or foreign access fishers in circumstances where they are vital for supporting the food security and livelihoods of coastal populations.

In this study, we demonstrated the importance of small-scale fisheries for coastal populations and highlighted the need for long-term management strategies that aim to enhance their ecological and economic sustainability. By analyzing small-scale fisheries post-landing trends in a remote coastal area in southwest Madagascar and taking a total economic valuation approach, we showed that coastal communities in the region depended almost solely on fisheries resources and coral reef ecosystems for income, livelihoods and food. In such remote regions, the exploitation of high value export products may have the potential to contribute to food security and poverty alleviation. However, high local market prices also create an incentive to overharvest, and without effective management strategies that ensure sustainability, overexploitation is likely. Moreover, with continuously increasing populations, impending decrease in catches and potential critical climate change impacts, the ability of small-scale fisheries to maintain their essential food security role is precarious. The establishment of locally managed marine areas, such as the one in our study site, may help to increase the benefits provided by small-scale fisheries, however, these initiatives need to be supported at the regional, national and international level. As small-scale fisheries are of considerable importance for millions of people throughout the world, our findings should catalyze national and regional policy makers to re-examine existing fisheries policies that neglect the sector, and spur researchers to better quantify the sector globally.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2013.05.011.

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