



Reconstructing the History and the Effects of Mechanization in a Small-Scale Fishery of Flores, Eastern Indonesia (1917–2014)

Victoria C. Ramenzoni*

Socio Economics Group, Harte Research Institute, Texas A&M University–Corpus Christi (TAMUCC), Corpus Christi, TX, USA

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*Correspondence:

Victoria C. Ramenzoni
victoria.ramenzoni@tamucc.edu

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The number of studies on small-scale fishing communities has grown considerably over the past 30 years. Evidence on how the process of mechanization and technological expansion has affected traditional small-scale fishers in peripheral regions, however, is less abundant. For areas like Eastern Indonesia that are now facing important challenges in governance and resource degradation, lack of information impairs the design of long-term environmental solutions. This article explores the changes in fishing participation and per capita seafood intake in a small-scale fishery in Flores, Eastern Indonesia over the past 100 years (1917–2014). By combining multiple sources of information (ethnographic, observational, nutritional, and historical) to reconstruct the story of stocks, fishing effort, and consumption of marine products, long-term trajectories, and trends in resource use practices are identified. Findings underline that mechanization and commercialization can have dire repercussions on food security and job stability within small-scale fishing sectors, especially if these processes are not part of comprehensive community development programs. The article concludes that understanding the outcomes of mechanization at the fringes of more centralized systems is essential to navigate the trade-offs among poverty reduction, economic growth, and environmental degradation.

Keywords: small-scale fisheries, development, mechanization, environment, historical ecology, nutrition

INTRODUCTION

Understanding local patterns of resource use has become a priority for coastal and fishery managers (Staples et al., 2004; Charles, 2011; Bavinck et al., 2015). To identify characteristics that may impede participatory governance, researchers have begun to explore the challenges that fishing communities face as they transition through processes of industrialization, mechanization, and market integration (Andersson and Ngazi, 1998; Bavinck et al., 2013). Historically, the transformation of local fisheries is often a result of intensive technological and capital development

Abbreviations: BPSE, Badan Pusat Statistik Ende; The office for Statistical Information for Ende District. BPSN, Badan Pusat Statistik Nusa Tenggara Timur; The office for Statistical information at the Provincial Level of Nusa Tenggara Timur. DKP, Dinas Kelautan dan Perikanan; Endenese Fishing Commission. CPUE, Catch per Unit of Effort; MSY, Maximum Sustainable Yield; MSE, Maximum Sustainable Effort; REPELITA, Rencana Pembangunan Lima Tahun; Five year development plans introduced by the Indonesian Government.

promoted by government and non-government agencies (MacFadyen and Corcoran, 2002). Yet, mechanization and commercialization can have dire repercussions on food security and job stability within small-scale fishing sectors, especially if these processes are not part of comprehensive community development programs (Ahmed, 1992; De la Cruz Modino and Pascual-Fernández, 2013; Donkersloot and Menzies, 2015). For example, higher capture efficiency through gear substitution, motorization, and the rapid adoption of new fishing devices can deflate market prices, increase competition, and introduce conflicts of access forcing individuals to exit the fishery (Bailey et al., 1987; Muhammad and Susilo, 1995; Andersson and Ngazi, 1998). In order to enhance the understanding of the impacts associated with development and modernization, this article explores the changes in fishing participation and per capita seafood intake in a small-scale fishery in Flores, Eastern Indonesia in the past 100 years (1917–2014).

While the number of studies on fishing communities has grown considerably since the 1980s, evidence on how the process of mechanization has affected traditional small-scale fishers after major industrial and technological fishing expansion is less abundant (Ahmed, 1992; Chuenpagdee, 2011, p. 23; Pascual-Fernández and De la Cruz Modino, 2011). Furthermore, research on subsistence fisheries in tropical regions and the social and environmental trade-offs associated with economic development has concentrated in studying densely populated areas (Cribb and Ford, 2009). Vast productive regions of the Eastern Indian Ocean, such as Eastern Indonesia, being at the fringes of more centralized policies have received little to no attention (Fox, 2005; Fox et al., 2009; Tull, 2009; Christensen and Tull, 2014).

Despite lower demographic densities, dependence on natural resources in these areas can be high as large sections of the population are still engaged in subsistence farming, fishing, and animal husbandry (Barlow and Gondowarsito, 2009; Resosudarmo and Jotzo, 2009; Stacey et al., 2011). These areas are also characterized by widespread poverty, high rates of infant mortality, and low incomes, which has made them a target for state and international aid. The tendency of government and conservation programs to concentrate in a reduced number of hotspots such as Raja Ampat in Papua New Guinea, Komodo National Park in Flores, or Wakatobe National Park in Sulawesi, and the lack of effective enforcement makes Eastern Indonesia an attractive location for illegal fishing, mining, and logging operations (Varkey et al., 2010; Mangubhai et al., 2012; Wright and Lewis, 2012). Unfortunately, limitations in the scope of environmental management efforts have consequences for ecological diversity that transcend the local and provincial scale.

The main goal of this article is to reconstruct the historical trajectories followed by Endenese communities in Eastern Indonesia as a result of development and modernization policies that occurred predominantly in central regions of the archipelago. Building from historical ecology and ethnographic research, this study discusses fishing participation and the consumption of marine products before and after the implementation of provincial plans to incentivize production. Analyzing what causes changes in resource use, the article reflects on the repercussions of capital-intensive fisheries, technological

modernization, and alimentary policies for communities on the fringes of economic and political centers.

A study of this nature contributes to the understanding of how practices and behaviors, albeit shaped by local policies, are also a byproduct of both the continuities and discontinuities in national and regional administration. It is contended that different patterns of development take shape as a dynamic expression of these realities and their effects at the household level (Allison and Ellis, 2001; Lenselink, 2002). Their history of resource use should be taken into account to generate new patterns of economic growth that are environmentally sustainable and do not exacerbate poverty (Béné, 2003; Allison and Kelling, 2009; Béné and Allison, 2010; Christensen and Tull, 2014). While considered peripheral in their geographical location, fishing communities like the Endenese are not isolated or disconnected from major economic centers (Wolf and Eriksen, 2010). Failure to capture these interconnections in policies and proposed governance solutions allows for the continuation of non-sustainable and illegal operations that have serious consequences for biodiversity conservation (Heazle and Butcher, 2007). As a consequence, fishery governance policies in Indonesia and other parts of the world will benefit from looking at the periphery to develop solutions across multiple geographical and institutional scales.

HISTORICAL RECONSTRUCTIONS IN DATA POOR FISHERIES

As shown by recent studies (Pauly and Zeller, 2014; Piroddi et al., 2015; Zeller et al., 2015), historical reconstructions can offer important lessons for future management policies seeking to modify local practices or to implement different systems of resource tenure. Rather than a definitive baseline, reconstructions represent an initial characterization of a fishery's production (Jacquet et al., 2010; Blythe et al., 2013; Pauly and Zeller, 2014). While many of these historical projections rely on official statistics, reports, and qualitative data such as interviews and anecdotal sources (Blythe et al., 2013), long-term observational or behavioral evidence is rarely available to correct retrospective estimates in data poor fisheries (Silvestre and Pauly, 1997). Additionally, reconstructions are often based on estimations of effort that do not consider the diversity of gear and capacity that a small-scale fishery might exhibit. This affects both the internal and external validity of findings, and constrains their implications.

In Eastern Indonesia, there are noticeable limitations on the coverage and quality of official statistics (Stacey et al., 2011). In the 1970s, the Indonesian central government imposed a general protocol for collecting fishery's information to address some of these issues (Bailey et al., 1987). The protocol is implemented unevenly at the provincial and regency level. For example, in Ende, the absence or lack of functionality of fishing auction offices has lead researchers to collect most measurements in regional markets. Measurements are then projected to calculate monthly and annual level figures. Estimations of yields often suffer from underreporting or the conflation of results with

other regencies. Along with serious problems in consistency and transparency, in many cases the process behind estimations remains unknown.

Complementing historical information with behavioral research, this article has three objectives. First, the evolution of the small-scale fishery from 1917 to 2014 is reconstructed through the generation of time series of landings, fishing effort, labor, and seafood consumption at the district level. Second, annual estimates of landings and per capita fish consumption are formulated from observational, nutritional, and ethnographic data. Proposed estimates, which in the case of fishing households condense prolonged research and track seasonal changes and can help contextualize historical reconstructions from official data. Third, the article explores potential explanations for changes in fishing participation over time.

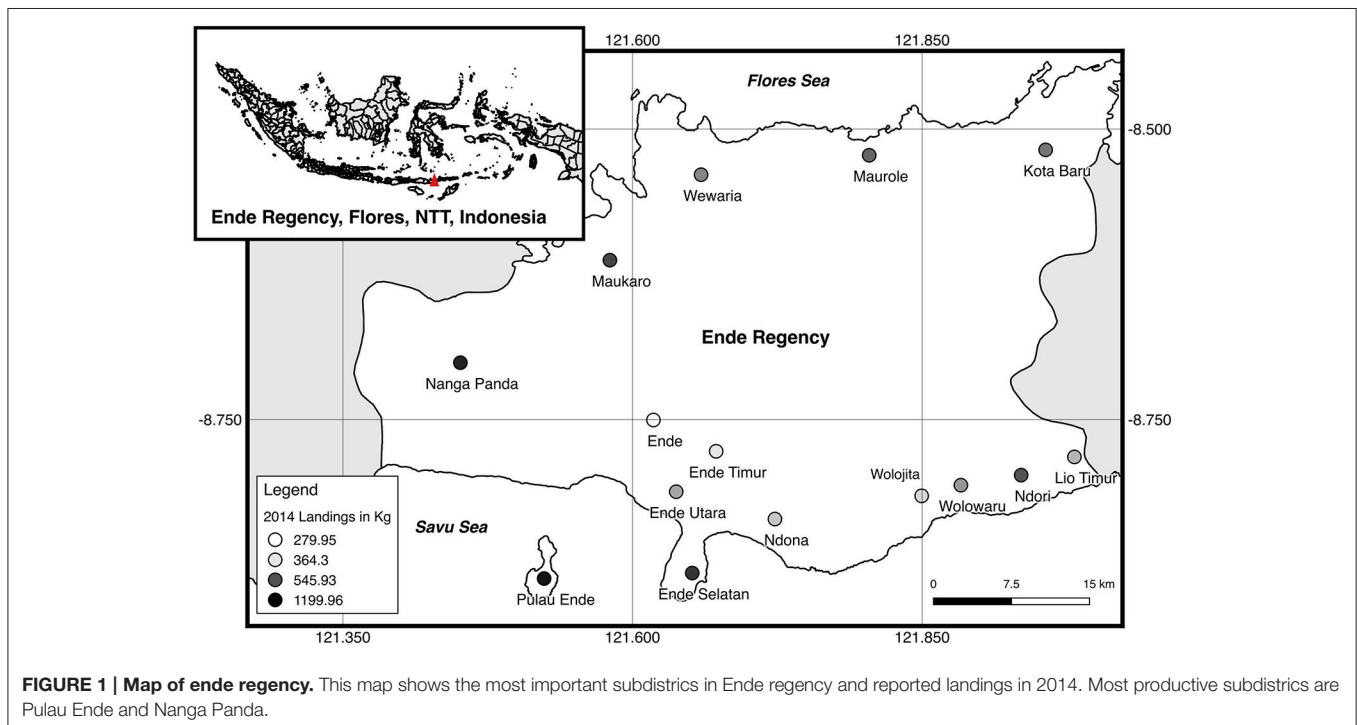
It is important to acknowledge that, given the lack of comprehensive records, reconstructed figures are preliminary. Suffering from limitations in terms of the measurement of effort and in the consideration of environmental factors, proposed reconstructions are corrected with systematic observations and extensive research on site. They represent an initial attempt at characterizing the production of the fishery and its significance in terms of production that can be of value to resource managers and scholars (Jacquet et al., 2010; Blythe et al., 2013; Pauly and Zeller, 2014).

METHODS

Study Site: The Endenese Fishery

The study area is in the District of Ende, Eastern province of Nusa Tenggara Timur, Indonesia (Figure 1). Limited to the

south by the Savu oceanic basin and to the north by the Flores Sea, this area is known for its coral reefs and pelagic fishing grounds. In 2014, the population was 280,076 people ascribing to different ethnic groups including Bajau and Bugis immigrants (BPSE, 1984–2014). Small-scale fisheries in Ende operate under the local fishing commission, following district, provincial, and central government management rules. As a consequence of decentralization, fishing rights are defined at the village level for areas that are <2 miles offshore. With the exclusion of trawling (pukat harimau), dynamite, and cyanide, there are virtually no restrictions to total allowed gear or any rules about bycatch. Fishing licenses (surat perikanan) are required if operating beyond the district area (>12 miles) in other regencies like Manggarai or Komodo. Only a small fraction of fishermen (<5%) venture on weeklong trips to other regencies in search for sharks, snappers, or large tunas. Hence, the majority of fishing occurs along the shorelines and relies on canoes, small-motorized plank boats, or medium size purse seiners (<5 tons; Ramenzoni, 2015). In 2011–2012, the local fishing commission reported around 2,500 boats according to a census of fishing effort. Survey data from sampled communities for the same period indicates negligible differences with official reports in the number of active fishermen. According to questionnaires of fishing profile, the most prevalent fishing gear includes small gillnets (mesh size of 2.5–12 cm), troll lines, and hand line fishing. Common captured species comprise Scombridae, Clupeidae, Lutjanidae, Serranidae, and Carangidae families (Ramenzoni, 2013). While bigger fleets out of the ports of Kupang and Benoa, Bali, operate pole and line fishing vessels in the offshore regions of the Savu and Timor Seas and in the Indian Ocean (Stacey et al., 2011), Ende has no medium or large scale fishing industry. There is also no fishing



auction in the regency and refrigeration is very limited. Most of the catch is sold at the regional markets.

In the past years, conservation and transnational institutions have called attention to the high level of non-sustainable exploitation and resource degradation in the Savu and Flores Seas (Ingles et al., 2008; Munasik et al., 2011; Achmad et al., 2013). Fishermen have observed sharp reductions of fish populations, with benthic, elasmobranch, and coral species suffering a dramatic decline (Fox, 2005; Blaber et al., 2009; Tull, 2009; Christensen and Tull, 2014). The action of foreign vessels has been reported since the early 2000s, which may further compromise the integrity of marine stocks. In 2013, there were talks and provincial plans for establishing dedicated coastal zones for conservation and ecotourism, and for attracting investment to develop fishing industries and fishing cooperatives (Munasik et al., 2011). More information on the historical context affecting Indonesian small-scale fisheries can be found in **Table 1**. The table shows a transition between an extractive colonial regime mostly concentrated in agricultural development to a nascent democratic republic, a military regime, and finally a neo-liberal democracy. The management of the fisheries reflected the need for economically sustainable food sources in the context of a rapidly growing population, echoing major trends observed in other parts of the developing world.

Catch Reconstructions

Approach 1: Historical Data and Archival Sources

Data were collected during three field seasons in May–August 2009, November 2010–January 2011, and June 2011–January 2013. Research objectives, protocols for data collection, and instruments were reviewed and approved by the Institutional Review Board of the University of Georgia (IRB 2010-10808-2) before any activities begun. Research permits were also procured through RISTEK, the Indonesian government agency that oversees international research and from the proper authorities (Propinsi NTT, Kabupaten Ende). Authors followed strict ethical procedures as outlined by the IRB and have no conflicts of interest to report. Archival research was conducted in Ende and Maumere (Flores, Indonesia), in Yogyakarta and Jakarta (Java, Indonesia), at the Royal Tropical Institute (Koninklijk Instituut voor de Tropen) in Amsterdam and at the Catholic Archives at Radboud University in Nijmegen (The Netherlands). The main sources of district level statistical information were the Bureau of Statistics of Ende (Badan Pusat Statistik Ende or BPSE), the Bureau of Statistics of Nusa Tenggara Timur Ende (Badan Pusat Statistik Nusa Tenggara Timur or BPSN), and the Fishing Commission of Ende District (Dinas Kelautan dan Perikanan or DKP). These offices produce numerous yearbooks and reports that were complemented and consolidated to derive time series.

The processes of reconstruction for population, landings, effort, and labor were completed by adopting a similar approach to Palomares and Heymans (2006) (Zeller et al., 2006, 2007, 2015), Piroddi et al. (2015), and Pauly and Zeller (2014). Reconstructions were informed by archival research, literature reviews, and the combination of multiple data sets from local and provincial agencies and FAO FISHSTATJ. Anchor points extracted from sources, were used to interpolate missing

data when information was not available. When assumptions were required, proposed values were highly conservative and corrected by consulting at least two historical sources. See **Tables 2, 3** for a description of data sources, anchor points, and estimations. Specifications are provided for particular years when calculations required adjustments. For example, **Table 2** presents information on demographic reconstructions while **Table 3** gives consideration to landings, effort, and number of active fishermen. In both cases, retrospective estimations are derived from anecdotal and colonial sources for the first half of the twentieth century; therefore, values should be considered as approximations. Information from neighboring districts such as Sikka and Kupang is used to control and extrapolate missing values. It is only at the beginning 1961 that official census data, local and regional statistics, and FAO reports become available. Figures from national, provincial, and district level sources such as BPSE and BPSN are reconciled by corroborating captures with yearbooks for other provinces. For more detail consult methodological annex.

Weights and transformations for reconstructions of landings, effort, and number of active fishermen.

To report landings and captures, the total amount of kilograms in tons is used without disaggregating by type of species or family. Capture is considered to be determined only by the level of fishing effort. Paucity of reliable meteorological datasets for the period before 1971 prevented the systematic consideration of environmental factors in reconstructions.

To standardize effort defined as number of boats, the different types of boats were weighted on the basis on their tonnage and potential optimal catch (Widodo et al., 2004). The estimation of catchability was very conservative and responded to observations of returns at the port of Ende (see Methodological Annex). To establish the effort for a year, weights were multiplied by the number and types of boats. The Catch per Unit of Effort or CPUE was calculated annually as the ratio between landings and effort.

Labor was operationalized as the number of fishermen including individuals with and without boats. To calculate the number of individuals fishing with boats (owners or crew members) the average sizes of crew by type of boat were used. Estimations of crew sizes derived from observations and historical sources (consult methodological annex and **Table 3** for more details). For fishermen operating without gear, a ratio of 0.60 to the total number of individuals operating with boats was initially implemented. This proportion reflected an estimate of gear (nets) to boats, and was adjusted throughout the series to reflect changes brought by military conflicts, mechanization, and intensification of effort.

Approach 2: Field Observations

From June 2011 until January 2013, the author resided in Ende and Pulau Ende where she conducted intensive ethnographic, observational, and ecological research with the aid of two local field assistants. In total 132 surveys and about 120 semi-structured interviews were carried out among active fishermen in the village of Ipy in Ende, and in Rendo Rate Rua, Ekoreko, and Meti Numba in Pulau Ende following purposive sampling techniques. During interviews, fishermen provided

TABLE 1 | Main historical events affecting a small-scale fishery through economic development programs and institutional policies in Ende, Nusa Tenggara Timur.

Period	Historical context and repercussions
1917–1929	<ul style="list-style-type: none"> Colonial policies concentrate on agricultural development of coconut tree plantations. Fishing activities in Ende are mainly for subsistence and at a lower scale than in other regions. Use of traditional gear.
1930–1940	<ul style="list-style-type: none"> The 1929's economic crisis inaugurates a period of famines. Decreases of 50% of 1,928 export volumes are reached in 1933. 1937 shows recoveries of exports to 80% of 1,928 volumes (Jones, 1966).
1941–1950	<ul style="list-style-type: none"> Occupation from Japanese Army. Japanese soldiers provided advice and taught local fishers how to use explosives. Shipping was strictly controlled in the Timor seas. General widespread shortage of boats after end of World War II. Independence from Dutch government in 1945. Sukarno becomes president and establishes the "guided democracy."
1951–1975	<ul style="list-style-type: none"> Indonesia began reporting fish landings to the Food and Agriculture Organization of the United Nations (FAO) in 1950. Important growth in effort, labor, and landings in late 1950s. Number of boats climbed 28% by 1955, and fishermen increased 40% by 1958 at national level (Krisnandhi, 1969). Change dominated by "Static expansion," intensification of fishing mostly through traditional practices. Beginning of large-scale trawling and purse seine operations in Western region of the archipelago. 1967 military coup inaugurates the transition to the "New Order" with Suharto. First REPELITA quinquennial economic development plan (1969–1974).
1976–1983	<ul style="list-style-type: none"> Plans REPELITA II and III. 1980 Trawling Ban. Agricultural Ministerial Decree 607/1976 on fishing zones grants small-scale fisheries access to reserved coastal areas. National Fishery Service develops plan to induce small-scale fishermen to motorize and modernize units (1975–1985). In 1977 the fishing port of Kupang is built.
1984–1998	<ul style="list-style-type: none"> REPELITA IV, V, and VI implemented. Efforts to increase seafood consumption and employment by creating subsidies and credit programs to fisheries, commercialization, distribution channels, and training. Mass credit programs in 1982 for mini purse seiners and gillnets in Western Indonesia reach Eastern provinces in 1988. Movement of exploitation toward the Eastern provinces of the archipelago. Fishing fleets based off Kupang began operating in the Savu Sea in 1991. In 1985, the government opens the fisheries of the Indonesian EZZ to the participation of foreign vessels.
1999–2014	<ul style="list-style-type: none"> Important policy changes. Decentralization of fisheries through Law No. 22/1999 (Local Autonomy Law) and later Law No. 32/2004. Agricultural Ministerial Decree 392/1999 establishes zones of exploitation based on vessel size and type. Inconsistencies emerge between these decentralization and licensing laws. Use of large purse seine nets to capture large pelagic stocks in Flores and Savu seas is forbidden. Fishermen and market vendors mentioned that about 15% of the catch sold at the market originates in other regencies. Inflows began around 2002. Creation of a National Medium-term Development 2004–2009 plan aims at increasing and revitalizing fisheries, especially tuna, seaweed, and shrimp. 2009–2014 Strategic Plan is passed. To empower fishermen, ensure food security, and to support the increase in marine capture at the level 0.5%/year until 2014.

information on fishing activities, seasonality, and historical and environmental changes in the fishery. Surveys allowed for a more systematic collection of data in relation to activity hours, gear used, average catch per season, catch sharing practices, income, and government or private support. In addition to fishing questionnaires and interviews, 113 households (adults) from two villages (Ipy and Rendo Rate Rua) were surveyed regarding their patterns of consumption of marine products. Weighing of portions and special foods was done with a 3,840 BLTBL™ Digital Nutritional Scale in Pulau Ende.

To monitor household fishing effort (the number of trips to capture fish) observations and voluntary diary logs were used at two villages (Ekoreko and Rendo Rate Rua) in Pulau Ende from September 2011 until July 2012 (10 months). The sample was

balanced according to type of gear and data collection methods, with 20 fishermen being monitored daily by the main researcher and 20 individuals completing daily self-reports. Participants for self-reports were recruited after 8 months of residence, based on informally observed fishing frequency. Incentives for completing the logs were offered weekly during control visits and included fishing hooks, line, coffee, rice, and sugar. A total of 1,515 (766 canoe, 749 motorboat) fishing trips were recorded, including hour of departure, return, type of boat and gear, and total number of fish caught by species. Fish could not be weighted, as the catch would be sold at sea or right after return to port. In all cases, species were recorded in the local name and then identified with Reef Fish Identification Guides during focus groups and interviews with fishermen (Allen, 1999; Allen et al., 2005).

TABLE 2 | Anchor points and main sources used for estimating population figures from 1917 to 2014.

Period	Anchor points	Main sources
1915–1930	1915, 1917, 1924, 1930	Suchtelen and Leroux, 1921; Metzner, 1982; Dietrich, 1989; Ardhana, 2005; Nakagawa, 2006
1931–1950		Broek, 1940; Jones, 1966; Metzner, 1982; Nakagawa, 2006
1950–1960	1952, 1954	Nakagawa, 2006
1961–1971	1961, 1971, 1975	SUSENAS, 1984
1972–2014	1980, 1983, 1984, 1990, 1993–2000, 2001–2014	BPSE, BPSN annual reports (<i>Ende Dalam Angka</i> and <i>NTT Dalam Angka</i>) and subject reports (<i>BPSN-SP, 1984–2014; BPSN-SSK, 1984, 2002; SUSENAS, 1984</i>)

In addition to fishermen, 33 full time vendors were interviewed at the regional market to explore inflow of fish from other regencies and relations between offer and demand for seafood. Participants were recruited following purposive sampling techniques. It is estimated that this represents about 75% of vendors operating at any given time. The semi-structured interview tool included questions about the daily averages of fish sold according to size and species. Averages were requested in terms of units of fish and not in kg, and for small pelagic individuals vendors were asked about the approximate number of buckets commercialized daily. Other questions included fluctuations in catches, the presence of vendors from other regencies, and prices.

Finally, ecological research involved the monitoring of meteorological conditions. Two weather Davis Vantage Pro stations were placed in Ende and Pulau Ende by the main researcher. Measurements included temperature max and minimums, humidity, barometric pressure, wind direction and intensity, and lunar cycle and were taken from August 2011 to December 2012 every half hour. This information was used to reconcile effort data and to explain phases with no activity or low catches.

Projecting resource extraction

To estimate resource extraction for the district, primary data obtained through household surveys was combined with observations of fishing effort (1,515 events). It is assumed that fishing observations and survey results were representative of the whole fishing population (~7,000 fishing households; BPSE) in the area of study; and that fisheries were mostly artisanal and subsistence based. Because returns of observed fishing expeditions were in number of fish and not in kilograms, catch was disaggregated according to species and the units of fish captured were multiplied by each species average weight. In 2011–2012, 9% of the catch composed by varied demersal and benthic organisms, and 91% small pelagic and coral reef individuals. *Kembung*, also known as short or Indian mackerel (*Rastrelliger brachysoma*) was the most frequent species captured.

A scombrid that inhabits shallow areas, *kembung* has an average weight that oscillates between 100 and 300 grams. A value of 200 grams was used as the standard weight per unit of fish. Also in 2011–2012, the mean CPUE estimated for small canoes was about 27.1 units of fish trip⁻¹ day⁻¹. This brings about a mean estimate of 7 kg trip⁻¹ day⁻¹. For motorboats, the mean CPUE was 49.8 units of fish trip⁻¹ day⁻¹, or approximately a mean of 12 kg trip⁻¹ day⁻¹. Results are very similar to estimates reported for Banggi subsistence and artisanal fisheries of Banggi, Malaysia (Teh et al., 2007, 2011). Annual captures are calculated by multiplying the mean observed CPUE of 2011–2012, 8.5 kg trip⁻¹ day⁻¹, by the reported number of days fishing (19 days a month, with 9 months of operation, totaling 171 days a year). This figure was then, multiplied by the number of active fishermen for a particular year to obtain the total amount of catches in kg. The estimate provided a second measure to qualify historical reconstructions.

Projecting consumption of marine products

To approximate of the amount of marine resources consumed by Ende, annual estimates of fish consumption were generated for both fishing and farming households (Table 4). Per capita annual consumption in fishing households was estimated through observations from nutritional surveys conducted in 2011–2012 among Endenese fishing households. Surveys assessed the frequency of fish consumption by main species per week and season and fish portion sizes. For farming households, estimates were derived from the 1984 national social survey (SUSENAS; BPSN, 1984–2014) and from nutritional research conducted in the regency in the early 1990s (Reinhard, 1997). In order to back cast rates to 1917, estimates were calculated with national per capita fish intake indices from FAO as well as academic and anecdotal sources. To elevate these values to the population level, intake estimates were multiplied by the number of farming and fishing households present in the area (see Annex).

Projected reconstructions have several limitations. For example, lack of reliable data of catch compositions from 1917 to 1984 prevented the inclusion of changes in consumption levels of different fish species that probably affected overall consumption patterns. In addition, changes in annual per capita intake and other measures were modeled in a linear way. Finally, surveys with vendors from the regional fish market of Mbongawani, Ende, were used to provide context on the offer and demand of fish products. All datasets supporting the conclusions of this article are included within the article and its additional files.

Data Analyses

All statistical analyses were conducted in JMP Pro 11. Simple correlation, regression, and exploratory cluster analyses were used to approximate the relation between changes in landings, effort, labor, seafood consumption levels, and population figures for the period 1951–2014. The years between 1917 and 1950 were not included in these analyses as reconstructions were based on extrapolations of numbers of fishermen and demography. Landings were log- transformed to reduce skewness in the

TABLE 3 | List of estimations and evidence used to reconstruct effort, landings, and number of active fishers from 1917 to 2014.

Period	Factors	Anchor points	Estimations and adjustments	Sources
1917–1929	Labor force	1917	<ul style="list-style-type: none"> Labor or the number of active fishermen, is estimated in relation to type of gear and vessel size. Projected increase of effort and labor force of 1.5% annually from 1917 to 1929^{a,b}. 	<ul style="list-style-type: none"> Suchtelen and Leroux, 1921; Dietrich, 1989; Ardhana, 2005; Koloniaal Verslag van 1908, 2015 Roos, 1872, 1877; Koloniaal Verslag van 1921, 2017; Koloniaal Verslag van 1908, 2015 Broek, 1940
	Landings	No	<ul style="list-style-type: none"> Landings are estimated using annual average capture per fisher multiplied by labor force. Annual average is the mean of three rates: 547 kg (Pekalongan in 1880s and early 1950s); 510 kg (Molukas, 1960s); and 460 kg (Nusa Tenggara 1950s). 	<ul style="list-style-type: none"> Veth, 1855; Roos, 1877; Weber, 1890, 1903; Suchtelen and Leroux, 1921 Burhamzah, 1970; Partadireja and Makaliwe, 1974; Semedi, 2003
1930–1940	Labor force and Effort	No	<ul style="list-style-type: none"> Number of fishermen estimated in relation to type of gear and vessel size. A general 3% annual increment in the labor force is projected for the decennial, with an additional 2.5% increment in effort for the period 1930–1933. 	<ul style="list-style-type: none"> Ardhana, 2005; Kartika, 2009 Broek, 1940 Jones, 1966
	Landings	No	<ul style="list-style-type: none"> Landings are estimated through labor force and average annual capture. 	
1941–1950.	Labor force and Landings	No	<ul style="list-style-type: none"> Landings are estimated through the labor force and average annual capture. Number of fishermen estimated in relation to type of gear and vessel size. Decrements of 50% from 1941 to 1945 given WWII. Progressive recovery to pre-war levels in 1951. 	<ul style="list-style-type: none"> Krisnandhi, 1969; Bailey et al., 1987; Roch et al., 1995; Butcher, 2004 Krisnandhi, 1969; Dick, 1987; Stacey et al., 2011
1951–1975	Labor force	1961	<ul style="list-style-type: none"> Labor force and effort derived from landings (1951–1960). Increase of 28% in 1961 is projected to accommodate changes in landings and national labor and demographic trends. After 1961, increases in the labor force account for changes in landings, effort, and changes in average capture by gear type. 	<ul style="list-style-type: none"> Kennedy, 1955; Brand, 1968, 1969; Krisnandhi, 1969; Burhamzah, 1970; U.S. Department of Commerce, 1977; FAO, 2015b Roch et al., 1995 Partadireja and Makaliwe, 1974 Jones, 1966
	Landings	No	<ul style="list-style-type: none"> Introduction of new technologies in Indonesia is accommodated with a lag of 5 years^c. Captures showed significant increments in 1961, 1966, 1969, and 1975. Improvements in landings and changes in technology are incorporated gradually to reach an annual capture per fisherman of 750 kg in 1975^d. 	
1976–1983	Labor force and Effort	1984–1988	<ul style="list-style-type: none"> Rate of growth in number of boats and number of fishermen is derived from 1984 to 1988 by type of boat. Rate is applied backwards to estimate number of boats and the amount of fishermen operating without gear. Decreases in the number of younger members of the population engaged in fishing are expected due to cohort effects and migration^e. Estimates are also adjusted to reflect incipient mechanization and changes in average capture by gear type^f. Important changes are observed in annual capture per fisherman (mean for the period is 2.2 tons). 	<ul style="list-style-type: none"> BPSE, BPSN annual reports, and subject reports. Burhamzah, 1970; Partadireja and Makaliwe, 1974; Bailey et al., 1987; Roch et al., 1995; Satria and Matsuda, 2004; Satria, 2009 Jones, 1966

(Continued)

TABLE 3 | Continued

Period	Factors	Anchor points	Estimations and adjustments	Sources
	Landings	1975–1983	<ul style="list-style-type: none"> Numbers of Total Fishing Domestic Product fixed at constant prices for 1975 are used to reconstruct landings from 1975 to 1983. 	
1984–1998	Labor force and Landings	No	<ul style="list-style-type: none"> Statistical information from the local district and the provincial level are harmonized to recreate the number of boats and landings in Ende from 1984 to 1999. 	<ul style="list-style-type: none"> BPSE, BPSN annual reports, and subject reports. Bailey, 1987; Susilowati, 1996; Heazle and Butcher, 2007; Sunoko and Huang, 2014
1999–2014			<ul style="list-style-type: none"> Statistical information from the local district and the provincial level are harmonized to recreate the number of boats and landings in Ende from 1999 to 2014. 	<ul style="list-style-type: none"> BPSE, BPSN annual reports, and subject reports. Satria and Matsuda, 2004; Barlow and Gondowarsito, 2009; Resosudarmo and Jotzo, 2009; Satria, 2009; Stacey et al., 2011

^aRate of increase in effort is approximated given the changes in agricultural production and exports and demographic growth for the period.

^bChanges in subsistence practices to minimize risks is a common strategy among fishermen and foragers around the world (Cashdan, 1990; Andersson and Ngazi, 1998; Tucker, 2007; Tucker et al., 2011).

^cTo reflect delays in the introduction of new initiatives in Eastern Indonesia, the change in fishery inputs is lagged 5 years (Butcher, 2004; Zeller et al., 2015).

^dAround 1970, East Nusa Tenggara reaches 22,900 fishermen; 460 kg annual capture. West Nusa Tenggara reaches 15,900 fishermen; 1.28 kg annual capture. These two figures are averaged to estimate improvements in annual capture rates in Ende.

^eCohort effects are demographic effects resulting from changes in the age structure of the population. In this case, effects respond to an increase in babies born after WWII and conflicts of Independence. By 1975, a steady rise in the share of middle aged (25–44 years of age) in the working population is a natural effect of the changes of the previous decennials (Jones, 1966, p. 66).

^fAlthough no evidence is available in district level documents, the years in between 1975 and 1983 showed important increases in landings suggesting the introduction of new gear. Individual capture rates were modified to reflect changes in technology (Bailey et al., 1987, p. 83).

TABLE 4 | List of parameters, weights, and evidence used to reconstruct consumption of marine products from 1917 to 2014.

Period	Parameters and estimations	Weights	Anchor points	Main sources	
1917–1940	Per capita annual intake of fish in Java and relation to Outer Islands ^a .	1.88	1917	Krisnandhi, 1969; Creutzberg et al., 1987	
		Average change of –0.03 per year	1927–1930		
		Average change of +0.02 per year	1931–1939		
		Average change of –0.01 per year	1940–1945		
		Average change of +0.05 per year	1946–1950		
	Number of fishing households.	20.395	1924		
1950–2013	Per capita annual intake of fish products in farming households ^b .	~9.5 kg for farming households in 1993–1994	1993–1994	SUSENAS, 1984 (BPSN); Reinhard, 1997; FAO, 2015a	
		~46.2 kg	2011–2012		Own observations
		45.436	2006		Nakagawa, 2006; BPS Ende; BPSE
45.973	2010				

^aAnecdotal information and nutritional publications were used to approximate values for the years 1917–1940.

^bFor the period 1950–2013, per capita rates provided by FAO Food Sheets were used (FAO, 2015a) and adjusted according to population changes.

data. To further study behavior and accuracy of reconstructions, paired-samples *t*-tests were used. First, the changes in the number of fishermen through time were evaluated through point analysis. Moving averages were calculated to smooth changes between individual data points, and the data series was partitioned into two periods for comparison (1951–1964 and 1965–1984). Second, the similarity between historical reconstructions of landings based on sources and official statistics and projections derived from observational data was assessed. In this second comparison, the series was also divided into two smaller temporal

levels (1975–2014 and 1951–1975) to compare the performance of different individual annual catch rates.

The Maximum Sustainable Yield (MSY) and Maximum Sustainable Effort (MSE) for the period between 1975 and 2014 were calculated to evaluate the state of stocks and potential excesses in effort. The time period chosen responds to the quality and reliability of data. Information about landings was obtained from provincial and district level reports and no historical reconstructions or projections were included. In order to approximate demersal and neritic productivity to evaluate the

state of the stocks, Dalzell and Pauly's log-linear models (Dalzell and Pauly, 1990; Tomascik et al., 1997) were applied. Through spatial statistical analysis primary productivity from 2011 to 2012 and bathymetry values were extracted for an area of 45 km from the port of Ende. The threshold of 45 km was selected as the maximum distance fishing boats might travel in one single trip given technological limitations (Semedi, 2003). It is assumed that, if oceanographic conditions were the same or better, MSY and MSE figures might reflect the potential productivity of fishing grounds in the early 1900s. Equation parameters can be found in Methodological Annex.

RESULTS

Historical Reconstructions: Changes in Landings, Effort, and Labor

Total capture by Endenese fishermen from 1917 to 2014 was estimated at $342,561 \pm 2,573$ tons. The values for the reconstructed time series can be found in **Table 5**.

Estimations of Ende's productivity for demersal and pelagic species, and including only Savu's fishing grounds, are placed around 5,900 tons a year at best biological levels. Considering this figure as a proxy measuring the sustainability of the fishery, it is possible to hypothesize that exploitation was not intense from the first decades of the 1900s and into the early 1980s. Annual mean captures fell between $2,290 \pm 1,600$ tons. In 1989 reconstructions indicate that stocks might have been intensively exploited or exploited beyond sustainable limits. Effort and capture numbers exceed the parameters recommended by the Schaeffer MSY model (**Figure 2**). Through the mid-1990s and early 2000s, catches showed important oscillations reflecting an overall mild increasing trend. The increment, however, is not proportional to the changes in effort, which might suggest an overall excess of boats. The decrease in catch per unit of effort between 1990 and 1985 is about two and a half times.

Observations of decreases in productivity are also supported by conversations and interviews with fishermen and market vendors. While changes in captures and landings were often discussed, fishermen also mentioned a modification in targeted species in the 1990s and 2000s. This shift was toward small pelagic stocks like mackerel tuna (*Euthynnus affinis*), skipjacks (*Katsuwonus pelamis*), sardines and anchovies (Clupeidae families), and scads (Carangidae families), and responded to the reduction of captures of large tunas and elasmobranchs, along with oscillations in the capture of reef and demersal species.

Concerning efficiency in captures, the reconstructed series of annual catch rates shows that individual productivity was relatively low until the beginning of the 1970s (**Figure 3**). The peak in fishing catch rates occurs in 1984, when the number of boats is 851 and the number of active fishermen is smaller in comparison to previous decades (BPSE). In 1989, the number of boats increases several orders along with the number of fishermen. Individual productivity, however, falls back to early 1970s' values. The following years bring a steep increase in catch rates, that peaks in 2003 and decreases again toward 2014, when annual individual productivity is 1,134 kg. The catch per unit of effort

TABLE 5 | Reconstructed time series of effort, landings, population, and number of active fishers at the regency of Ende, Flores, province of Nusa Tenggara Timur, Eastern Indonesia.

Year	Effort ^a	Landings ^b	Population	Fishers
1917	216	717,035	68,653	1,418
1918	219	751,930	69,771	1,487
1919	222	786,814	70,890	1,556
1920	226	821,709	72,008	1,625
1921	229	856,593	73,127	1,694
1922	233	891,487	74,245	1,763
1923	236	926,382	75,364	1,832
1924	240	961,266	76,482	1,901
1925	243	996,160	77,601	1,970
1926	247	1,031,044	78,719	2,039
1927	251	1,065,939	88,314	2,108
1928	254	1,100,834	97,910	2,177
1929	258	1,135,718	107,505	2,246
1930	265	1,169,789	117,100	2,313
1931	271	1,210,732	117,639	2,394
1932	278	1,253,107	118,177	2,478
1933	285	1,296,966	118,716	2,565
1934	289	1,302,844	119,254	2,576
1935	294	1,308,732	119,793	2,588
1936	298	1,314,621	120,332	2,600
1937	302	1,320,498	120,870	2,611
1938	307	1,326,387	121,409	2,623
1939	312	1,332,265	121,947	2,635
1940	316	1,338,153	122,486	2,646
1941	291	1,231,101	123,025	2,435
1942	265	1,120,302	122,486	2,215
1943	238	1,006,942	122,688	1,994
1944	214	906,248	122,890	1,795
1945	187	788,436	123,092	1,561
1946	200	843,626	123,294	1,671
1947	214	902,680	123,496	1,787
1948	229	965,868	123,698	1,913
1949	245	1,033,479	123,900	2,046
1950	262	1,105,822	129,807	2,190
1951	279	1,271,300	135,713	2,332
1952	286	1,437,900	141,620	2,397
1953	295	1,480,400	143,712	2,467
1954	307	1,591,000	145,804	2,566
1955	313	1,623,800	146,322	2,619
1956	318	1,651,200	146,841	2,663
1957	310	1,605,900	147,359	2,590
1958	320	1,660,400	147,878	2,678
1959	307	1,592,600	148,396	2,569
1960	315	1,636,900	148,915	2,640
1961	404	2,083,800	149,433	2,977
1962	420	2,145,700	152,423	3,065
1963	449	2,208,300	155,413	3,155
1964	503	2,334,100	158,402	3,334
1965	574	2,637,800	161,392	3,768

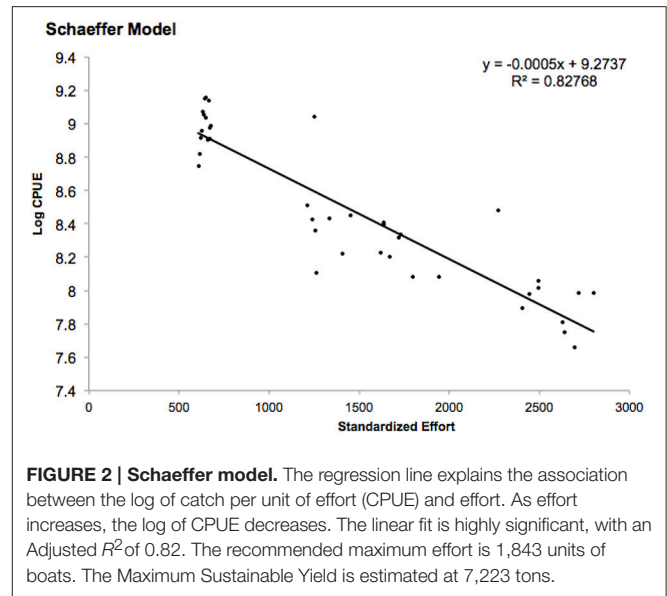
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TABLE 5 | Continued

Year	Effort ^a	Landings ^b	Population	Fishers
1966	551	2,980,100	164,382	4,257
1967	557	2,732,300	167,372	4,120
1968	563	2,906,000	170,362	3,983
1969	570	3,143,400	173,351	3,845
1970	576	3,251,500	176,341	3,708
1971	582	3,291,800	179,331	3,571
1972	589	3,345,400	179,755	3,434
1973	595	3,527,000	180,179	3,296
1974	601	3,762,100	180,602	3,159
1975	608	3,814,700	181,026	3,022
1976	614	4,148,200	192,113	2,884
1977	620	4,630,100	202,613	2,747
1978	627	4,883,700	198,593	2,610
1979	633	5,514,000	202,752	2,472
1980	639	5,456,300	201,609	2,335
1981	646	6,081,100	204,090	2,198
1982	652	6,191,800	206,571	2,061
1983	658	4,856,100	209,053	1,923
1984	665	6,183,500	214,015	1,786
1985	670	4,958,600	214,605	1,803
1986	674	5,320,400	215,213	1,816
1987	679	5,432,800	215,820	1,839
1988	650	5,447,700	216,428	1,685
1989	2,696	5,715,100	217,635	6,211
1990	2,629	6,483,400	218,841	5,921
1991	2,638	6,126,000	221,000	5,930
1992	2,405	6,457,800	222,012	5,307
1993	1,406	5,241,600	224,900	3,424
1994	1,453	6,790,100	226,500	3,700
1995	1,619	6,049,800	228,000	4,022
1996	1,213	6,032,700	229,400	3,173
1997	1,335	6,120,200	230,700	3,504
1998	1,722	7,060,400	231,800	4,276
1999	1,730	7,200,100	232,600	4,305
2000	1,638	7,250,200	232,270	4,127
2001	1,638	7,345,100	237,156	4,127
2002	2,271	10,974,700	234,579	5,633
2003	1,251	10,603,800	238,486	3,463
2004	1,262	4,174,000	241,826	3,442
2005	1,256	5,357,000	241,929	3,441
2006	1,667	6,102,000	237,555	4,431
2007	1,243	5,669,700	238,040	3,183
2008	1,797	5,801,300	238,127	4,825
2009	1,945	6,305,300	238,195	4,882
2010	2,443	7,125,900	260,605	6,466
2011	2,496	7,565,500	265,761	6,578
2012	2,496	7,868,500	267,262	6,578
2013	2,719	7,988,700	278,538	6,932
2014	2,800	8,210,940	280,076	7,178

^aEffort is a standardized measure representing here the number of active boats. The figure is weighted to reflect differences in types of boats based on tonnage and potential optimal catch. See Table 2 for specifications.

^bCalculated in kilograms.



shows a similar behavior, with steeper increments in 1984 and more pronounced declines in the 2000s (Figure 3). Overall, both measures indicate a decreasing trend for the past 30 years and provide further evidence of intensive exploitation of stocks.

The number of active fishers, or the labor force (Figure 4), exhibits a somewhat linear increase in reconstructions from 1917 to the early 1940s, and then from 1945 to the mid-1960s. In 1965 the working force averages 4,000. This figure reflects important increases in the number of fishermen at the national level as well as the impacts of population recovery and higher fertility rates after the war. The inference is substantiated in government documents, reports, and academic articles from the 1950 and 1960s that indicate important changes in the structure of age cohorts, mechanization, and landings in the country. The first year for which official statistics are available on labor composition in the district is 1984. Then, about 1,800 people seem to be participating in the fishery.

If comparing the two temporal markers, between 1966 and 1984, a 60% reduction in the working force seems to occur. As it will be discussed later, this sharp contraction can be an effect of overestimation errors given the use of anchor points, extrapolations from other regencies, and anecdotal evidence during the reconstruction. It can also be a factor of source accuracy and of changes on how statistics were reported at the district, provincial, and national levels. Another hypothesis that will be presented later is that the contraction of the labor force can be explained by the nature of the mechanization process in Ende. This speaks of a lack of policies directed at small-scale sectors of the fishery, of the instability in the job market, and of a complex scenario of demographic changes and migration.

After 1989, marked oscillations occur in the number of individuals participating in the fishery. Data points for this period are derived from official reports at the district and provincial levels with few inconsistencies (BPSE). When comparing the most recent decades against the reconstructions for the decennials 1950s, 1960s, and 1970s and for the early years of

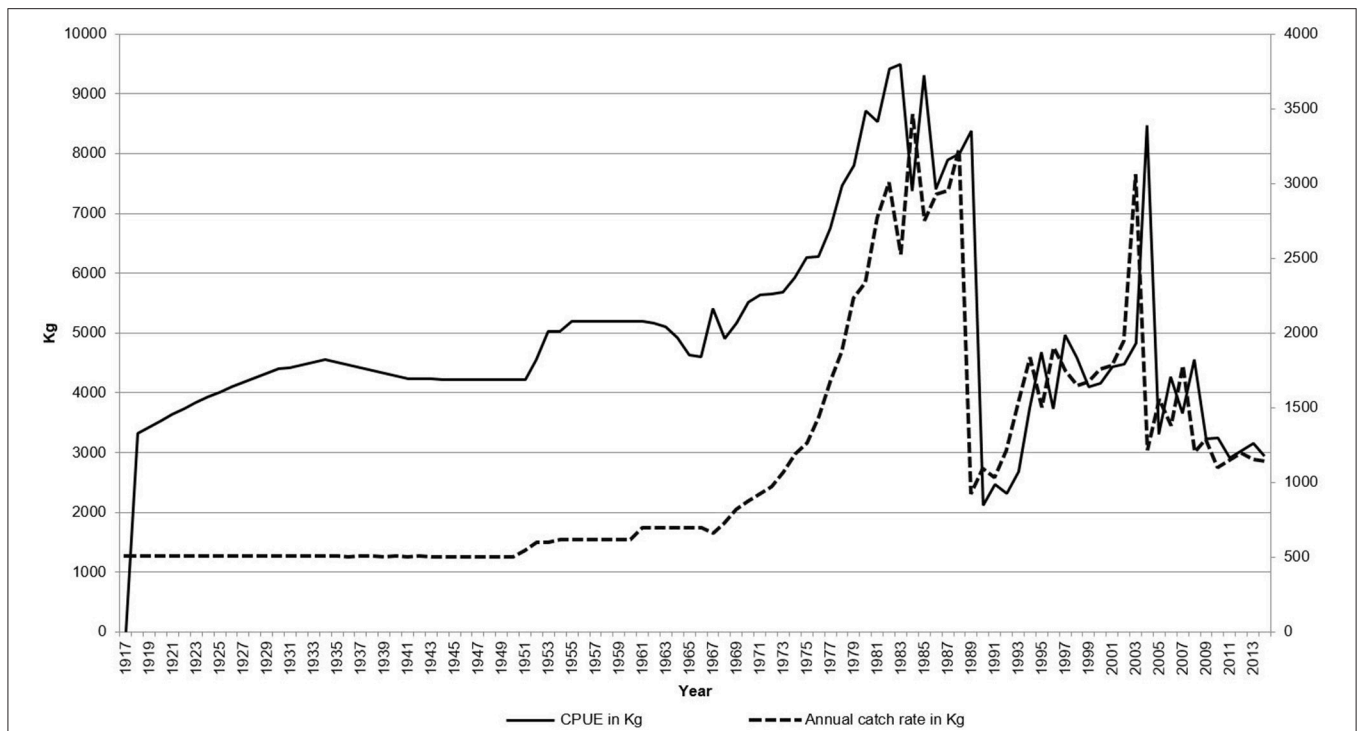


FIGURE 3 | Time series of annual catch rates and CPUE. Chart shows the evolution of catch rates (annual landings divided by number of fishermen) and CPUE (catch-per-unit of effort; landings divided by standardized number of boats) for the period 1917–2014. Observe that both reconstructed measures peak in the mid-1980s, to decline in early 1990s. A second peak occurs in early 2000s.

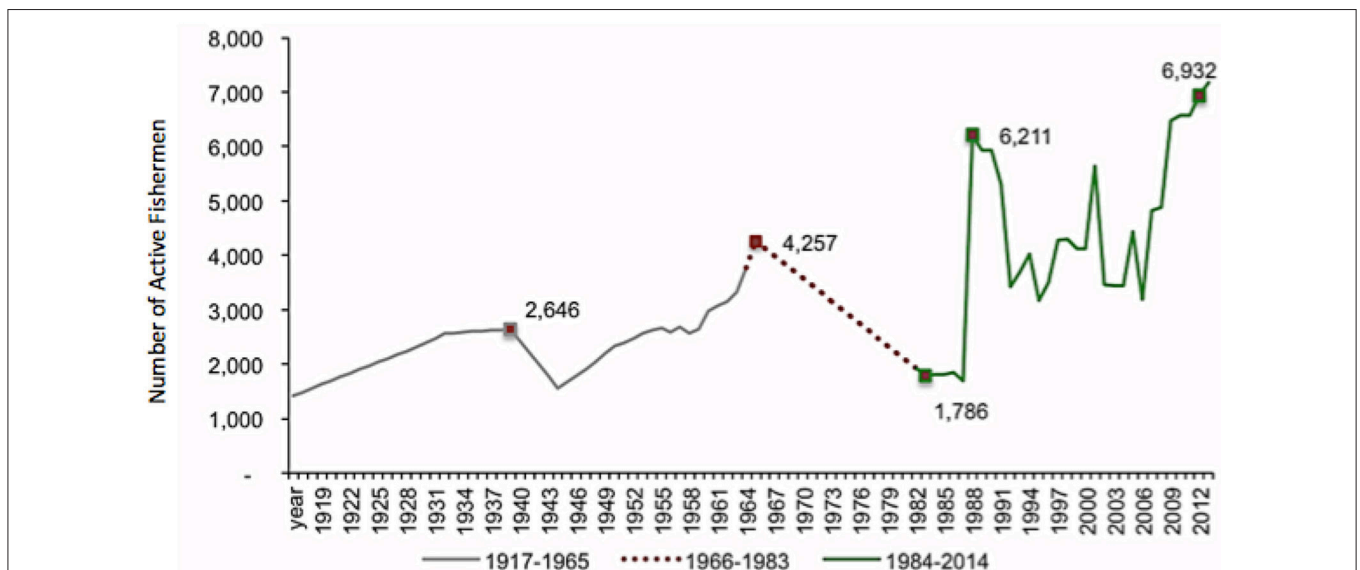


FIGURE 4 | Time series of numbers of active fishers as reconstructed by historical data. The curve shows a bimodal distribution (Normal Mixture), with a potential change in moving averages occurring in the mid-1980s.

1980s, a change can be observed in how the number of fishermen evolves over time. If the period is divided into two smaller equal sections (1955–1984, 1985–2014), and moving averages for each section are analyzed with a *T*-test for paired samples, differences

are found to be significant ($T = 4.00$; $p = 0.0004$). Barring problems with accuracies in the reconstruction, the differences between the two temporal sections indicate that the number of jobs became even more unstable or variable after 1989.

TABLE 6 | Reconstructed time series of Per Capita seafood consumption and total consumption for Ende regency, Flores, province of Nusa Tenggara Timur, Eastern Indonesia.

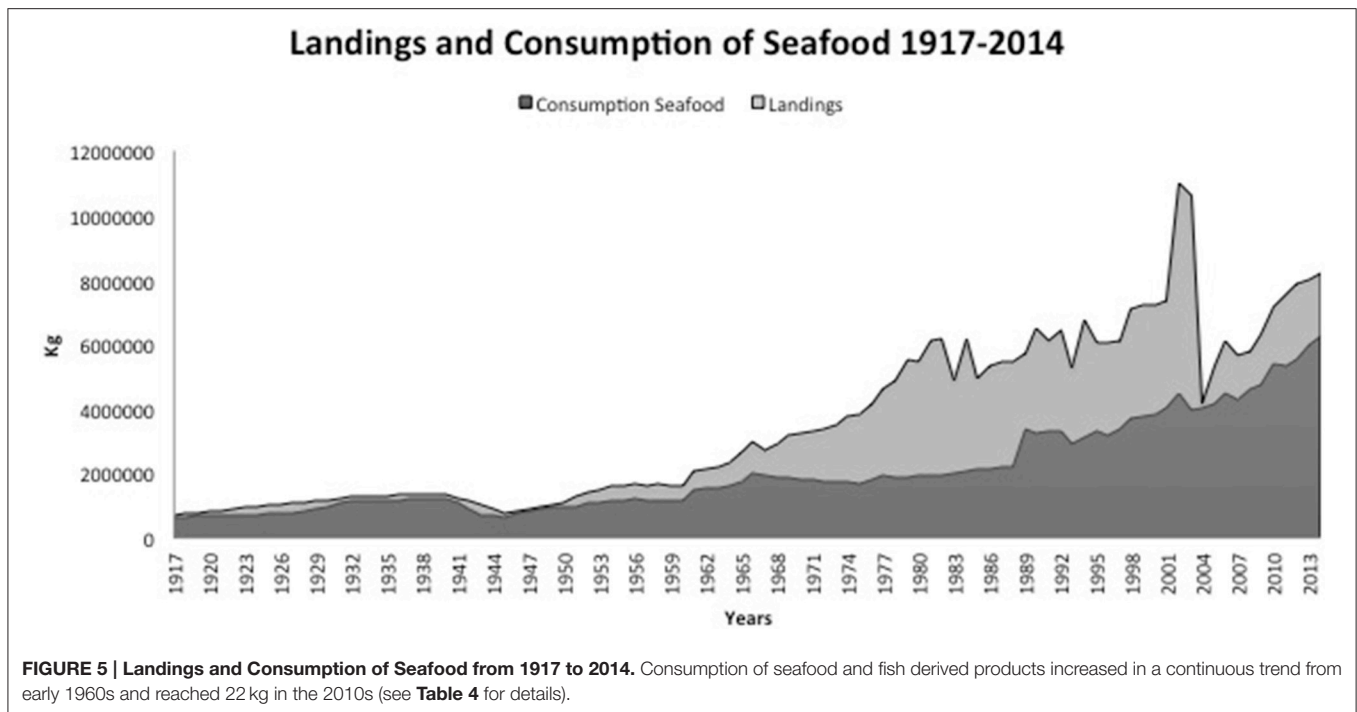
Year	Per capita ^a	District consumption ^a
1917	9.39	644,585
1918	9.39	655,201
1919	9.39	665,825
1920	9.39	676,441
1921	9.4	687,065
1922	9.4	697,681
1923	9.4	708,305
1924	9.4	718,921
1925	9.4	729,545
1926	9.4	740,157
1927	8.9	785,997
1928	8.61	842,932
1929	8.27	889,384
1930	8.15	953,795
1931	9.49	1,116,966
1932	9.64	1,138,927
1933	9.78	1,161,586
1934	9.78	1,166,706
1935	9.78	1,172,061
1936	9.78	1,177,417
1937	9.91	1,197,319
1938	9.91	1,202,741
1939	10.09	1,230,532
1940	9.78	1,198,369
1941	8.78	1,080,260
1942	7.01	858,544
1943	5.88	721,133
1944	5.62	690,237
1945	5.31	653,789
1946	6.19	763,526
1947	6.61	816,598
1948	7.06	873,350
1949	7.53	933,393
1950	7.58	984,450
1951	7.24	982,261
1952	7.71	1,092,026
1953	7.64	1,098,441
1954	7.73	1,127,129
1955	7.79	1,139,967
1956	8.2	1,203,765
1957	7.96	1,173,268
1958	7.59	1,122,956
1959	7.67	1,138,589
1960	7.7	1,146,228
1961	10.03	1,498,521
1962	9.98	1,521,606
1963	9.73	1,511,546
1964	10.14	1,606,040

(Continued)

TABLE 6 | Continued

Year	Per capita ^a	District consumption ^a
1965	10.83	1,747,288
1966	12.04	1,979,532
1967	11.45	1,915,874
1968	10.81	1,841,859
1969	10.71	1,855,965
1970	10.36	1,826,338
1971	10.01	1,795,684
1972	9.74	1,751,344
1973	9.5	1,710,832
1974	9.52	1,719,806
1975	9.38	1,698,843
1976	9.4	1,805,438
1977	9.39	1,903,164
1978	9.38	1,862,101
1979	9.36	1,898,101
1980	9.53	1,921,606
1981	9.48	1,933,851
1982	9.36	1,933,606
1983	9.69	2,024,990
1984	9.67	2,069,873
1985	9.79	2,100,599
1986	9.97	2,145,309
1987	10.09	2,177,977
1988	10.2	2,207,287
1989	15.33	3,337,032
1990	14.81	3,241,646
1991	14.92	3,297,868
1992	14.82	3,289,607
1993	12.98	2,919,815
1994	13.81	3,127,402
1995	14.5	3,305,200
1996	13.95	3,201,045
1997	14.66	3,381,087
1998	15.84	3,672,613
1999	16.29	3,789,700
2000	16.61	3,858,001
2001	17.03	4,038,502
2002	19.13	4,487,259
2003	16.51	3,936,972
2004	16.73	4,046,620
2005	17.2	4,160,337
2006	18.97	4,507,339
2007	17.92	4,265,946
2008	19.34	4,605,329
2009	19.77	4,708,673
2010	20.81	5,422,489
2011	20.03	5,321,903
2012	20.65	5,517,740
2013	21.38	5,955,905
2014	22.27	6,237,529

^aCalculated in kilograms.



Reconstructions of consumption of marine products: changes in per capita intake of seafood and market demand

Total consumption of seafood for the district is estimated at $201,300 \pm 1,400$ tons from 1917 to 2014 with average per capita fish consumption of 11.2 ± 4 kg per year (Table 6, Figure 5). The average is slightly inferior to estimates reported for Pacific Island countries (Zeller et al., 2006, 2007). This is not unusual, as Endenese fisheries have remained at subsistence levels. Only a much-reduced proportion of captures is destined to exports and this includes demersal and coral fisheries as well as elasmobranch products. Changes in fish intake have most likely occurred with modifications in catch per unit of effort over time and economic programs. The most critical developments influencing fishing households seem to have taken place after the 1960s and 1970s with the intensification of effort, increases in catch rates and landings, and the reduction of prices for fish products (BPSN). Farming households also began to incorporate seafood regularly into their diets with changes in roads and infrastructure along with health and nutritional programs.

Interviews with market vendors showed that, on any given day, the demand for seafood was capable of absorbing, and sometimes exceeded, offer. The market brings together about 125 vendors a day, a large fraction of which depends on partners from other towns to obtain fish. On average, five trucks a day (load of 350 kgs) come from the neighboring regencies of Sika (Sika and Maumere) and Nanga Keo (Bajawa). A conservative approach suggests that $\sim 15\%$ of what is reported as sold could have originated in other regencies. This inflow of fish started about 10–12 years ago and may correspond to the high levels of fluctuation in landings experienced in that period. Finally, it should be noted that even when total captures are growing,

landings for some species have declined. For example, market vendors mentioned that small tuna and sardine are among the species most frequently sold, while on average, only 1 unit and a half of large size fish is commercialized per vendor per day.

Historical reconstructions vs. observed effort

To evaluate how historical reconstructions of landings matched retrospective projections for 1950–2014 based on observed effort, *T*-tests for paired samples were used (Table 7). Comparisons did not include the period between 1917 and 1949 as both reconstructed series relied on number of active fishermen to calculate landings. However, starting 1950, historical reconstructions built from FAO datasets and provincial or local statistics, while retrospective projections interpolated captures by multiplying observed annual capture by number of fishers per year (see Section Methods). For the most recent period spanning from 1975 to 2014, no differences were found between historical and observed reconstructions relying on an average capture of $8.5 \text{ kg trip}^{-1} \text{ day}^{-1}$. While there is an absolute difference of 81,826 kg between the means of both groups, the *T*-test reports a non-significant difference and a 0.54 correlation. For 1950 to 1975, the comparison of historically reconstructed landings and observed landings with an annual capture average of $4.75 \text{ kg trip}^{-1} \text{ day}^{-1}$ has a correlation of 0.73. The *T*-test is also non-significant (DF: 24) and the absolute difference between the two means is 152,589 kg. Overall, these results seem to indicate that a change of annual average captures per fisher per trip occurred in the late 1960s, early 1970s. The lower correlation in 1975–2014 between the two series could be a reflection of the oscillation in landings as shown in the data, as well as instability in individual capture rates.

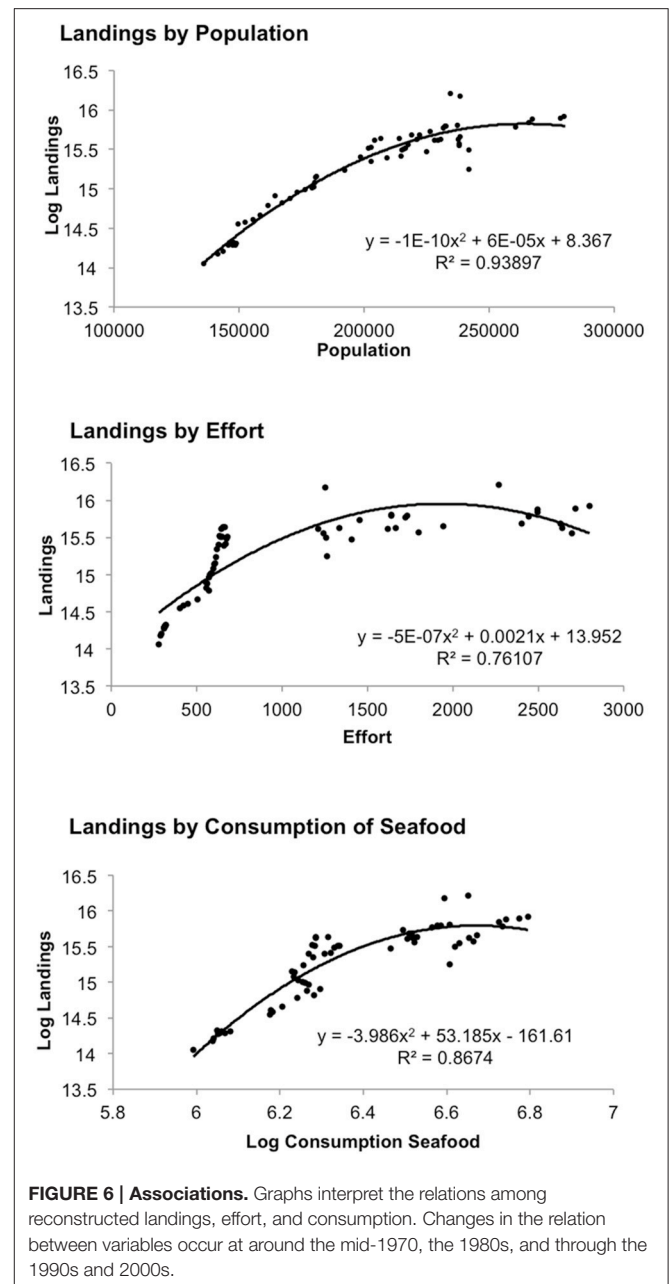
TABLE 7 | Comparisons between reconstructions and observed effort.

Period	Mean reconstructed	Mean observed	Statistics
1950–1975	2,388,616	2,541,205* *at 4.5 kg trip ⁻¹ day ⁻¹	T-test is non-significant DF: 24 Correlation: 0.73
1975–2014	6,263,471	6,345,297* *at 4.5 kg trip ⁻¹ day ⁻¹	T-test is non-significant DF: 39 Correlation: 0.54

To explore the associations between factors, simple regressions with landings as the dependent variable and population numbers, projected effort, and consumption as explanatory variables (**Figure 6**) were used. In all cases, polynomial fits modeled associations better with respective R^2 of 0.93, 0.76, and 0.86. Changes in the relation between variables happen at different temporal times, mostly around the mid-1970, the 1980s, or the 1990s. For example, while landings and population numbers seem to increase somewhat proportionally until 1975, in 1976 data points become more dispersed. The relation between consumption and landings for the period 1951–2014 also shows higher dispersion in the 1980s and 1990s and some clustering. Regarding effort, the distribution of observations is more clearly clustered around three groups of data points (2200, 1200, and 680 units of standardized effort). Clusters capture the transitions and oscillations in variables occurring from the 1970s to the 2000s.

DISCUSSION

Historical reconstructions complemented by observational and nutritional information provide evidence of the singular trajectory followed by Endenese fishing communities over the past 100 years. At the local level, Ende transitioned from a cash crop economy with marginal use of marine resources, to a society that consistently relies on fish as a source of protein and is intensively exploiting its stocks. This transition is seen in the reconstructions as a 10-fold increase in total landings and a five times increase in per capital fish consumption among farming sectors. Moreover, the fishery quadrupled the number of active fishers throughout the years. But, while the district's landings, marine products consumption, and population show increasing figures over time, this growth is not uniform. For example, the number of active fishermen, CPUE and annual capture rates, or standardized effort, do not seem to follow a simple linear trend, and show changes in mean values over time. To understand how these variables fluctuate, it is important to consider the larger historical context in which changes occurred. Ende embodies the case of a fishery that, because of its peripheral location, was exposed to discontinuous development and modernization policies. In tandem with the modifications in effort and consumption patterns instituted by the policies themselves, this characteristic probably exacerbated



non-sustainable outcomes and had important effects within communities.

The germ of modernization and mechanization policies can be historically placed in the new economic direction adopted by post-Independence Indonesia during the late 1960s. Emerging from centuries of colonial domination, the new Indonesian state concentrated its efforts to boost the local economy and reduce staggering rates of poverty. In fisheries, actions were directed at achieving self-sufficiency in seafood production and the substitution of imports. These actions took place, initially, in the Western provinces of the archipelago. From 1951 to 1968 a sharp rise in the number of fishermen and fishing boats was experienced (Yamamoto, 1980). As a consequence,

the amount of fish landed doubled by the end of 1960s (Krisnandhi, 1969). In 1967, with a change in government and the beginning of the New Order, a new economic direction was introduced. A set of quinquennial development programs, named REPELITA (*Rencana Pembangunan Lima Tahun*), run from 1969 to 1999 and oriented efforts predominantly to the development of the agricultural industry and food production. New regulations created an inflow of foreign investment that was directed at the modernization of fishing sectors (U.S. Department of Commerce, 1977). The growth of offshore fishing was encouraged, giving impetus to the creation of new fishing fleets and the industrialization of operations. With the introduction of trawlers and large purse seiners, exports rose from USD \$2 million in 1969 to \$85 million in 1975 (U.S. Department of Commerce, 1977, p. 96). Modifications in productivity and gear had dire consequences to both fishermen and fisheries alike (Bailey, 1987; Bailey et al., 1987; Roch et al., 1995).

In Eastern Indonesia and particularly in Nusa Tenggara Timur, systematic changes associated to the development of productive sectors began to occur in the 1970s (Partadireja and Makaliwe, 1974). The implementation of the first REPELITA economic programs initially focused on communication, transportation, and infrastructure. Although it was recognized that development had to start by cementing the local economies, agricultural sectors only received 5% of the total budget. Within this distribution, most funds were allocated to animal husbandry and improvement of agricultural crops like cotton and coffee. In 1970, fishery contributions to the GDP of the province were almost three times the amount reported for 1969 suggesting important advances in captures (Partadireja and Makaliwe, 1974, p. 35). What created these increases remains uncertain. However, the allocation for fishery expenditures rose in 1972/1973 budgets (Partadireja and Makaliwe, 1974, p. 38). This was similar to what happened in the provinces of Bali, Moluccas, and Irian Jaya (Bailey et al., 1987). In these regions, captures of demersal and pelagic stocks improved with the introduction of large-scale gear. Increases in capture, however, should not be considered as an indication that modernization was taking place uniformly and across all fishery subsectors (Bailey et al., 1987, p. 42). In many locations, and especially in the eastern regions, practices still continued to rely on traditional boats (Partadireja and Makaliwe, 1974, p. 47; Butcher, 2004).

Mechanization of small-scale fisheries in the Nusa Tenggara province was very limited until the 1980s. The adoption of new technologies was constrained by a general lack of credits and government policies directed at facilitating technological transfer (Cribb and Ford, 2009). Other limitations were the availability of new equipment and gear, and the distance to centers of technological dissemination. With changes in infrastructure and communication brought by REPELITA plans in the 1970s and early 1980s, and the operation of large scale fishing fleets in the Eastern regions, exposure to technology gradually increased. As it has been observed for other small-scale fisheries in Southeast Asia and in Africa, the assimilation of new technologies probably modified the composition of fishing effort within communities and created competition between modernized and traditional fishermen (Ahmed, 1992; Andersson and Ngazi, 1998). Higher

capture efficiency through gear substitution and motorization can deflate market prices, forcing households to invest in new technologies or to exit the fishery altogether (Bailey et al., 1987; Muhammad and Susilo, 1995). While this reservoir of labor could be absorbed by other sectors in the fishing industry, such as seafood processing or commercialization, in Eastern Indonesia there were very few industries, even less so directed at fisheries (Resosudarmo and Jotzo, 2009). Most likely, additional work effort engrossed the lines of infrastructure, commercial, and government service employment. But, where motorization outpaced both industrial and economic growth or effort concentrated in the hands of few, local fishing communities were most likely becoming poorer (Semedi, 2003).

The process of labor contraction was anticipated in the Western provinces by the evaluation of results from the 1973 national fishing survey by the FAO (Yamamoto, 1980). For example, it was noted that in early 1970s there was an excessive number of small-scale fishermen in the northern coasts of Java, and in other regions like Riau in Sumatra. Increases in efficiency of the fisheries in these regions were to be attained by reducing the numbers of individuals directly engaged in fishing (Yamamoto, 1980). While the creation of a middle fishing sector through technological development was highly desirable as a means to reduce poverty and to improve productivity of non-industrialized areas, it was also recognized that mechanization alone was not an adequate solution (Muhammad and Susilo, 1995). If the process was not accompanied by the introduction of economic alternatives at the community level, it could exacerbate economic deficiencies and be the “cause of serious social problems” (Yamamoto, 1980, p. 6.1.5; De la Cruz Modino and Pascual-Fernández, 2013; Donkersloot and Menzies, 2015). In fact, dramatic conflicts arose between trawlers and small-scale fishermen in the immediate years throughout the Western Provinces and Irian Jaya (Bailey, 1987; Roch et al., 1995).

In the case of Ende, historical reconstructions showed that the number of active fishermen experienced gradual increases until the 1940s, when labor fell due to military conflicts. Activities recovered after the cease of hostilities, and continued to grow steadily into the 1960s. After 1965, a marked decrease of almost 60% in the working force occurred in the lapse of 20 years. High instability and posterior recovery of the number of individuals engaged in the fishery happened between 1987 and 2014. The particular trajectory followed by the labor force in the years in between 1965 and 1984 could be a result of inaccuracies in the process of reconstruction. For example, they may reflect errors in anchoring values due to underestimation of earlier figures. However, it could also be interpreted as evidencing an economic contraction of the number of individuals operating in the fishery given the introduction of technological innovation and mechanization. Additionally, demographic effects might explain a reduction of available labor as the age structure of the population pyramid shifted. While statistical information is scant, there are several pieces of evidence that may support this conclusion.

- For instance, fishermen mentioned that nylon nets began to substitute heavier traditional materials such as cotton or

vegetal fibers by the late 1960s. Sailboats remained in use until the mid-1980s, when access to outboard engines became more common. Older fishermen did not recall any government aid directly supporting their activities, but emphasized that improvements were based on individual initiative. Traditional shipping and trade between Ende, Bima, and Ujung Padang, made the circulation of these innovations possible. However, not all fishermen had the means to mechanize, and credits were infrequent. The first mention of provincial support and an increase in fishing effort occurs in 1989 (BPSE). This is not surprising, as REPELITA programs seem to have focused on aquaculture and the development of infrastructure such as ports.

- Secondly, considering that no trawling or industrial fishing has ever been established or operated off Ende, observed increases in landings in 1976 might point to an improvement in the efficiency within the small-scale sector. The composition of effort in 1984 shows the existence of 62 motorboats (<5 tons) and of 6 larger-scale motorized vessels (>5 tons). This is markedly different from 1917, where the number of ships of similar tonnage totaled 14.
- Thirdly, whereas close to 1970, the number of fishermen in East Nusa Tenggara was roughly placed at 23,000 (Partadireja and Makaliwe, 1974, 47), in 1983 there were 15,611 fishing households, or ~18,000 fishermen (BPSE, vi). Hence, indicating reduction of 22% of the number of individuals engaged in the fishery. The report also mentioned that while productivity was kept high, the contraction in manpower in all agricultural sectors was compensated by a migration of workers to areas of commerce and infrastructure.
- Finally, the impacts of demographic changes and inter-island migration should not be overlooked. After WWII, population numbers experienced significant rates of growth (Jones, 1966). As a result, by late 1950s, an inflow of younger individuals was available to join the active work force. By 1965, a renewed emphasis of migration programs, and the creation of jobs in other spheres of the local and regional administration could have meant a reduction of individuals willing to engage in fishing. By 1975, the number of people in the age bracket between 25 and 44 years of age probably tied or surpassed the younger cohorts. Combined to low life expectancy rates (Resosudarmo and Jotzo, 2009) the effect of an older population of workers may have also contributed to lower levels of active engagement in the fishery.

In addition to changes in the composition of the labor force, with the expansion in mechanization in 1970s–1980s, the sustainability of marine resources in the archipelago at large started to decline. In the western Indonesian seas, the central government responded by introducing several measures that sought to protect small-scale fisheries, such as a general ban on all trawling operations. Moreover, during the mid-1980s the general government began to pursue the rationalization and fair allocation of economic growth in the sector by passing several pieces of legislation to protect smaller sectors. This direction took an important role in the quinquennial economic plans, REPELITA V (1989–1994) and REPELITA VI (1994–1999).

In 1985, however, the central government modified licensing processes and allowed for the creation of joint ventures. As a result, the fisheries of the Indonesian EZZ became open to the participation of foreign vessels (Sunoko and Huang, 2014).

In Eastern Indonesia, where degradation was not perceived as a threat, the central and the regional government pursued an increase in the number of large vessels fishing for skipjack and tunas operating off ports such as Benoa, Bali and Kupang, Timor. In Ende, modernization continued to prosper with rapid growth in the number of motorized boats. In 1989, through provincial programs, effort quadrupled (BPSE). However, by 1993, the number of boats and landings declined almost 30% suggesting a reduction of fish stocks. Evidence from reconstructions and interviews suggests as signs of overfishing or overexploitation (Reitz, 2004; Carder et al., 2007). It is also in 1992 that Flores suffered a devastating earthquake and tsunami that may also account for the changes in effort. In the following years, landings recovered showing a slow increasing trend due to provincial aid (BPSE). But, this trend was not stable. Throughout the mid-1990s and early 2000s, the level of effort oscillated given new decentralization policies and repercussions of the 1997/1999 El Niño-La Niña events. For example, changes in landings and catch compositions were experienced in other fisheries in Eastern Indonesia in the years before and after 1997 that may have influenced active participation in the fishery (Blaber et al., 2005; Stacey et al., 2011). Tied to success in landings and sustainable aid, the labor force also experienced fluctuations. It is also at this time that immigration to Malaysia and neighboring countries began to rise (Barlow and Gondowarsito, 2009).

At the general level, REPELITA VI marked the beginning of decentralization efforts in natural resource management of fisheries, forestry, and irrigation to provincial and local authorities (Susilowati, 1996). However, the implementation of decentralization policies run into several impediments that include lack of personnel trained in fisheries and lack of trust among different institutions (Satria and Matsuda, 2004; Barlow and Gondowarsito, 2009). All of these limitations seemed to be true in the case of Ende. In 2002, another influx of boats increased effort with landings reaching unprecedented numbers for 2002 and 2003. In 2004, yields fell to 60% of previous reported numbers, remaining at similar or lower levels in comparison to the previous decade. This result may reflect the conflation of incentivization policies with environmental pressures introduced by 2002–2004 El Niño-La Niña events. Changes in ecological conditions probably created new stressors to threatened fishing stocks. The level of effort was incentivized to counterbalance diminishing yields and thus, leading to the 2004 decline.

By 2005, a presidential regulation enacted the National Medium-term Development 2004–2009 plan. The program included an improvement in provision and data accuracy, the development of fishing facilities and handling systems, and the empowerment of the tuna, seaweed, and shrimp fisheries. None of these measures, however, created significant changes in the district of Ende. While informants mentioned the introduction of seaweed programs and training, only a few fishermen were selected to participate and efforts were hindered by favoritism

and corruption. When this research was carried out (2009–2012), support from the regional fishery was scant and irregular and mostly directed at intensification through the introduction of *lampara* boats (middle purse seiners). Going against the long-standing independent and individualistic character of the fishery, fishermen that wanted to access gear or engines needed to form smaller groups of three to four to receive any support. Nowadays, the fishery remains at large of subsistence scale. *Lampara* boats are growing and encroaching into coastal fishing grounds. With a tonnage that averages 4 of sardines, anchovies, and small pelagic fish, the proliferation of these boats are favoring the concentration of the fishery into a few hands. Ende may be at the brink of a new transition that could mean once again the contraction of the working force and the loss of operational independence by the smallest fishermen.

The future remains unknown for small-scale fishermen in Ende. With the establishment of marine protected areas in the Savu through a presidential decree in 2009, local district offices have taken new steps into addressing environmental concerns (Munasik et al., 2011; Achmad et al., 2013). Whether these new guidelines will be at odds with the pressures toward intensifying the fishery and achieving sufficiency in food production or whether they may be successfully reconciled, remains to be seen.

CONCLUSION

Through historical ecology and ethnography, this article explored the impact of development and modernization policies among small-scale fisheries in Ende, Eastern Indonesia. Within fishery management, the transformation of local fisheries has often been seen as a result of intensive technological and capital development promoted by government and non-government agencies (MacFadyen and Corcoran, 2002). While true in other contexts, modernization is a relatively recent undertaking in Ende and has followed a rather fragmented and discontinuous process leaving a particular set of tracks. Endeneze fisheries have experienced different gradients of transformation that speak of diverse and complex trajectories in the adoption of technological innovation (Ahmed, 1992). Understanding these trajectories is central to advancing fair regimes of resource use.

For example, when mechanization had not been properly regulated, the increasing competition by more efficient boats has resulted in the concentration of resources, the use of damaging fishing practices, and environmental degradation. The opportunistic nature in which policies were implemented has also meant that benefits from advancements were not equally shared among the parts, creating instability in the labor market and further eroding households' economic sufficiency. At present times, the situation has become more critical due continuous pressure toward modernization and stocks experiencing important changes in composition and stability.

As new regimes of governance are being proposed at the provincial level to address resource depletion and damaging fishing practices, it is important to see how small-scale fisheries are not isolated relicts of tradition. Even when considered peripheral in their geographical location, fishing communities

like Ende are not disconnected from trade or technological centers (Wolf and Eriksen, 2010). And while they have been relegated in government priorities, they have become very attractive to illegal fishing operations that include shark finning (Christensen and Tull, 2014). In these cases, is through Chinese middlemen that fishermen acquire much desired technological innovations and new fishing gear. Not accounting for these interconnections within policy and governance mechanisms has serious consequences for biodiversity conservation. Ultimately, environmental degradation reverts to the long-term sustainability of local livelihoods within the community and contributes to exacerbate poverty.

Almost 10 years ago, Heazle and Butcher proposed that to prevent further depletion of marine resources, we should pursued management solutions as “integral parts of a broader regional strategy that takes into account the political and economic circumstances of the region” (2007, 282). Historical reconstructions can help us elucidate how different patterns of development take shape. Understanding the outcomes of mechanization at the fringes of more centralized systems is essential to navigate the tradeoffs among poverty reduction, economic growth, and environmental degradation.

LIMITATIONS OF THE CURRENT STUDY

There are several limitations with the current study. Like other historical reconstructions of small-scale fisheries, this article relies on effort data that may provide an incomplete characterization of the intensity of resource harvesting activities. Given the nature of small-scale fisheries, the large diversity of gears and equipment used makes the systematic consideration of effort an arduous task. Direct monitoring of fishing behavior and landed captures is also difficult due to the flexibility of practices and schedules among individual fishermen. This creates some issues in the estimation procedures that should be acknowledged. Second, while observations and extensive archival and participant observation research were used to contextualized estimates, there are also risks of underestimation given the lack of information in terms of illegal operations in this particular region of the Savu. In addition, it is important to observe that the MSY model suffers from limitations for no biological estimations of growth or survival are available to correct inferences. Calculations might be reflecting thus the intensity of effort instead of real biomass numbers. Finally, environmental fluctuations affecting stocks have not been considered in the projections. The absence of meteorological datasets makes the assessment of the role of environmental fluctuations challenging. Future studies will address these shortcomings.

ETHICS STATEMENT

Institutional Review Board from The University of Georgia. Verbal informed consent was used to collect data for this study.

(a) Interviews/Short Interviews/Surveys:

- (1) Participants were provided with a prior informed consent document informing them of the purpose of the

investigation, the data collection process, benefits, and potential risks.

- (2) The content of the prior informed consent document was discussed verbally with each participant for their approval.
- (3) Participants were asked to give consent to their participation in the study.

(b) Time Allocation (Scans, focal follows, fishing logs):

Observations of actions conducted by individuals were registered by the researcher. Previous authorization to conduct such observations was solicited with the consent document.

AVAILABILITY OF DATA AND MATERIALS

The datasets supporting the conclusions of this article are included within the article (and its additional files). All datasets

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and sources used if not included in the document are available upon additional request to the author.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and approved it for publication.

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SUPPLEMENTARY MATERIAL

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