



Growing Into Poverty: Reconstructing Peruvian Small-Scale Fishing Effort Between 1950 and 2018

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Small-scale fisheries are globally marginalized by management institutions; thus, they have to endure the consequences of ineffective regulations, environmental uncertainty, social traps and market inequity. Small-scale fisheries in Peru, one of the world's leading fishing countries, are important contributors to national employment, food security and gross domestic product. Yet, relatively little is known about these fisheries and their evolution, except for the fact that the Peruvian small-scale fleet size is rapidly increasing. Here, we reconstructed small-scale fishing effort across time and developed several indicators using it to assess changes in the fleet's fishing efficiency and economic performance. Segmented regression analysis was used to identify statistically significant breakpoints and changes in their trajectories between 1950 and 2018. Our results suggest that fishing effort has strongly increased, and at much faster rates than the catches, particularly since 2006. The combined effect of these trends results in significant declines in the fleet's ratio indicators (i.e., catch per unit of effort, revenue per unit of effort, and fisher's incomes relative to Peru's minimum wage), suggesting that the growing fishing effort is unsustainable and uneconomic. The behavior of these indicators differs within the fleet, depending on the vessel's main fishing method. Most small-scale fishers are currently living in relative poverty. Yet, fishers using the least selective fishing gears, or engaged in illegal fishing, had the most stable incomes over the past decade. These findings are discussed in detail by exploring the social, legal and economic drivers fostering fleet growth. Finally, a list of general recommendations aimed at improving fisheries sustainability and fisher's wellbeing was produced, based on the local context, fisheries literature and common sense.

Keywords: small-scale fisheries, fishing effort, catch per unit of effort, revenue per unit of effort, relative income, uneconomic growth, fisheries enforcement, Peru

INTRODUCTION

Small-scale fisheries are globally marginalized by management institutions, and thus have to endure the consequences of ineffective regulations, environmental uncertainty, social traps and market inequity (Pauly, 2006; Salas et al., 2007; Finkbeiner et al., 2017; Chuenpagdee and Jentoft, 2019). Peru has one of the world's largest fisheries catch (FAO, 2018), although most of it is anchoveta (*Engraulis ringens*), a low-value fish mainly caught by industrial vessels and used overwhelmingly for fishmeal production (Gutiérrez et al., 2017). However, most of Peru's marine landings used for direct human consumption (i.e., used to partially satisfy local seafood demand and supply international seafood markets) are caught by the local small-scale fleet (Christensen et al., 2014). According to national regulations, this fleet is composed of small vessels (i.e., total length ≤ 15 m, hold capacity ≤ 32.6 m³), equipped with one or multiple manually operated fishing gears, that target marine living resources for commercial purposes (SPDA, 2019).

As in other developing countries (Schuhbauer and Sumaila, 2016), Peruvian small-scale fisheries play an important role in the national economy. In 2009, 54 thousand people were employed as small-scale fishers generating a revenue of 0.61 billion USD (Christensen et al., 2014). Moreover, as their landings provide raw materials for the secondary and tertiary sectors of the economy, 2.2 jobs and 3.5 USD were additionally generated in seafood value chains for every job and dollar made at sea (Christensen et al., 2014). However, small-scale fisheries remain relatively understudied, poorly regulated and subjected to ineffective enforcement of input (e.g., fishing areas and seasons, fleet size, and vessel dimensions) and output (e.g., total allowable catches and minimum-landing sizes) controls (Sueiro and De la Puente, 2015; Gutiérrez et al., 2016; Monteferri et al., 2017; SPDA, 2019).

Recent studies show that the Peruvian small-scale fleet is growing rapidly (Castillo et al., 2018), and now targets a more diverse portfolio of species over fishing grounds that are expanding both geographically and bathymetrically (Marín et al., 2017). This has allowed their catches (in volume) to increase over time, even when the average length and annual landings of traditionally targeted coastal species follow declining trends (CEDEPESCA, 2013; Mendo and Wosnitza-Mendo, 2014). Although these are pressing concerns, several factors have contributed to dulling their relevance in the public eye. These include, but are not limited to: the relative size of the small-scale fishery in comparison to the industrial fishery, the high environmental variability of the Peruvian marine ecosystem, the large number of stakeholders involved in addressing small-scale fisheries management, the limited resources allocated to strengthening and enforcing regulations, and the lack of clear objectives and indicators to assess the success of management strategies over time (Sueiro and De la Puente, 2015).

The reported increases in fishing effort observed around the world (Anticamara et al., 2011; Greer et al., 2019) continue to raise concerns about the sustainability of the targeted resources and the wellbeing of peoples that depend on them for their livelihoods and nutrition (Watson et al., 2012; Link and Watson, 2019). Thus, this paper aims at reconstructing small-scale fishing

effort in Peru, seeking to highlight the extent at which it has grown over time and assess its impact on the fishery's performance and fishers' economies.

MATERIALS AND METHODS

Reconstructing Small-Scale Fishing Effort

Peruvian small-scale fishing effort was reconstructed following the *Sea Around Us* fisheries data reconstruction framework (Zeller and Pauly, 2016), aiming to improve the local resolution of previous attempts that sought to estimate global fishing effort (Greer et al., 2019). This process included: identifying and sourcing official and alternative sources of time series data on the number of vessels in the Peruvian small-scale fleet and their characteristics; developing data 'anchor points' in time using all available information; interpolating data for the periods between anchor points; estimating small-scale fishing effort based on validated predictor variables; and constructing confidence intervals for the fishing effort reconstruction over time, by scoring uncertainty in data sources, assumptions and methods used (Zeller and Pauly, 2016; Greer et al., 2019).

Two indicators were used to estimate annual fishing effort: nominal and effective effort. Nominal effort in year t (nE_t) is the product of the number of boats in the fleet (N_t), their average capacity (P_t) and the average number of days they spend fishing during the year (D) (Greer et al., 2019).

$$nE_t = N_t \times P_t \times D_t \quad (1)$$

Effective effort in year t (E_t) is the product of nE_t and a technological creep factor (Tc_t). The latter accounts for the progressive increases in fishing power that result from improvements in gear design, fish detection and catch handling methods (Belhabib et al., 2018; Palomares and Pauly, 2019).

$$E_t = nE_t \times Tc_t \quad (2)$$

Local stakeholders and regulators describe fishing operations, and administer the small-scale fleet based upon vessel type, gear and target species (Christensen et al., 2014; Sueiro and De la Puente, 2015; Marín et al., 2017; SPDA, 2019). Thus, this reconstruction aimed at segregating fishing effort by fishing gear and vessel type. This required: (a) estimating changes in small-scale fleet size over time; (b) defining subgroups within the small-scale fleet; (c) estimating vessel capacity from total length; and (d) developing working hypotheses for the extent of their technological creep.

Estimating Changes in Small-Scale Fleet Size Over Time

Data anchor points for the total number of small-scale vessels in Peru were extracted from the literature (Table 1). Fleet size was interpolated linearly between anchor points except for two periods: (i) 1988–1995, when ancillary data on 'vessels year of construction,' retrieved from INEI (2012), were used to reconstruct annual fleets size increments, and (ii) 2016–2018

TABLE 1 | Data sources used for the reconstruction and uncertainty 'scores' used for evaluating the quality of the small-scale fleet size time series, with their corresponding confidence intervals, based on Mastrandrea et al. (2010) and Zeller and Pauly (2016).

Data score	Scoring criteria	Confidence interval		Years were applied	Sources of data
		– %	+ %		
Very high	High agreement and robust evidence	10	10	1997–2012	Wosnitza-Mendo, 1992; Escudero, 1997; Estrella et al., 2006, 2010; Marín et al., 2017
				2015	Castillo et al., 2018
High	High agreement and medium evidence or medium agreement and robust evidence	20	20	1982	Wosnitza-Mendo, 1992
				1986–1996	Reconstructed using data from INEI (2012)
				2013–2014	Linear interpolation
Low	High agreement and limited evidence or medium agreement and medium evidence or low agreement and robust evidence	30	30	1953–1969	FAO, 2018; Greer et al., 2019
				1970–1980	Berrios, 1983
				1981	Linear interpolation
				1983–1985	FAO, 2018; Greer et al., 2019
				2016–2018	Projection
Very low	Low agreement and low evidence	40	40	1950	Caravedo, 1979
				1951–1952	Linear interpolation

when fleet size was projected assuming a conservative growth rate of $3\% \text{ year}^{-1}$. All vessels reported in fleet size surveys or census were assumed to be in operation, unless otherwise stated in the source data. Confidence intervals were assigned to annual fleet size estimates based on the level of uncertainty in data sources (i.e., very high, high, low, and very low reliability), in accordance to previous fisheries data reconstructions (Table 1).

Defining Subgroups Within the Small-Scale Fleet

The Peruvian small-scale fleet is composed of several sub-fleets simultaneously operating at sea (Castillo et al., 2018), and each sub-fleet (e.g., small-scale longliners) is composed of métiers or combinations 'vessel types' and 'fishing methods' (Christensen et al., 2014).

Small-scale vessels were grouped into four categories, or vessel types, based on their length class and propulsion system (i.e., VT1: non-motorized vessel with $L < 8 \text{ m}$; VT2: non-motorized vessel with $8 \text{ m} \leq L \leq 15 \text{ m}$; VT3: motorized vessel with $L < 10 \text{ m}$; VT4: motorized vessel with $10 \text{ m} \leq L \leq 15 \text{ m}$) (Greer et al., 2019). Anchor points for the number (or percentage) of motorized vessels in the fleet were extracted from literature (Caravedo, 1979; Wosnitza-Mendo, 1992; Estrella et al., 2006, 2010; INEI, 2012; Castillo et al., 2018). Vessel motorization was linearly interpolated between anchor points and projected to 2018 by applying the average annual rate of increase estimated for the 2012–2015 period.

In 2012, a census of small-scale fishermen and their vessels was conducted along the Peruvian coast (INEI, 2012). Using vessel-specific information extracted from this dataset (e.g., its year of construction, total length and propulsion system), we were able to estimate, on annual time steps, the proportion of active motorized vessels according to their length (i.e., VT3 and VT4), and the average vessel length for all vessel types between 1950 and 2012. Annual average vessel lengths by vessel type were projected from

2013 to 2018 by using a 5-year moving average starting with the 2008–2012 period. The rate of change of the proportional contribution of each vessel type to the total fleet exhibited between 2008–2012 was used to project the number of vessels by vessel type between 2013 and 2018 (Castillo et al., 2018).

Next, métiers were defined by allocating fishing methods to vessel types. The main fishing methods used by Peruvian small-scale vessels across the time series include: (i) gillnets, (ii) handlines, (iii) hands or tools (i.e., compressed air divers), (iv) longlines, (v) purse seine nets, (vi) squid jigs, (vii) traps, and (viii) trawl nets (Sueiro and De la Puente, 2015; Marín et al., 2017; Castillo et al., 2018).

Small-scale vessels in Peru can change fishing gears seasonally or use more than one fishing gear at the time (Sueiro and De la Puente, 2015). However, most vessels use a single or main fishing method throughout the year (Estrella et al., 2010). Hence, we assumed that vessels only used one fishing method per year. Annual estimates of the total number of small-scale vessels using individual fishing methods were available for 1982 (Wosnitza-Mendo, 1992), 1996 (Escudero, 1997), 1997–2012 (Estrella et al., 2006, 2010; INEI, 2012; Marín et al., 2017), and 2015 (Castillo et al., 2018). The relative contribution of each fishing method to the total fleet, and vessel types, were estimated for these anchor points. An additional artificial anchor point for these parameters was constructed based on descriptions of the small-scale fleet around the start of the time series (Caravedo, 1979; Coker, 1910). Data were then linearly extrapolated between anchor points (i.e., 1951–1981, 1983–1996, and 2013–2014). Time series were then projected to 2018 using a 3-year moving average (starting from 2013 to 2015) of each methods' proportional contribution to the total fleet. The proportion of vessels using each fishing method by vessel type were carried forward without change (i.e., if 20% of VT3 used gillnets in 2015, we assumed that 20% of VT3 also used gillnets in 2016, 2017, and 2018).

Finally, five assumptions were used to formulate a working hypothesis of the evolution of non-motorized métiers over time: (I) non-motorized vessels only used handlines and gillnets across the time series, (II) the use of gillnets by non-motorized vessels decreased over time and was highest at the start of the time series, (III) the use of handlines by VT2 increased over time, (IV) the easiest path for fishers seeking to become new vessel owners is to obtain a non-motorized vessel and equip it with handlines, and (V) non-motorized vessels equipped with gillnets have a higher likelihood of producing larger yields, allowing their vessel owners to acquire an engine and transition to a different vessel type over time (at a faster rate than unmotorized vessels using handlines).

Estimating Vessel Capacity From Total Length

Annual average vessel capacity (P_t) by métier (in $\text{kW} \cdot \text{vessel}^{-1}$) was approximated using the estimated annual average vessel length (L) by vessel type. For métiers using motorized vessels, P_t was inferred from L (in meters) through previously validated constants, such that $P = 0.436 \times L^{2.021}$ (Anticamara et al., 2011; Greer, 2014). Alternatively, constant P_t values were assigned for métiers using non-motorized vessels consistent with those found in published literature (i.e., VT1: $P_t = 0.37 \text{ kW} \cdot \text{vessel}^{-1}$; VT2: $P_t = 0.75 \text{ kW} \cdot \text{vessel}^{-1}$; Greer et al., 2019).

Developing a Working Hypothesis for the Technological Creep by Métier

The Peruvian small-scale fleet experienced a slow technological creep over time resulting in larger fishing areas (i.e., increases in engine power), longer fishing trips (i.e., greater use of isothermal boxes with ice or insulated holds) and reductions in the time spent searching for target species (i.e., increased cellphone coverage and/or usage of sounders and GPS navigators) (Alfaro-Shigueto et al., 2010; Estrella and Swartzman, 2010; Sueiro and De la Puente, 2015; Marín et al., 2017; Castillo et al., 2018).

Technological creep trajectories were heterogeneous across métiers (Table 2). Annual creep factors (T_{ct}) might seem 'conservative' in comparison to other studies (Palomares and Pauly, 2019). However, they were developed based on the local history of the fleet and exclude increases in fishing power associated with increases in vessel size. The latter were directly incorporated in our calculations through the vessels' capacity (P_t).

Non-motorized vessels and their operations have changed very little over time (Coker, 1910; Sueiro and De la Puente, 2015), thus retaining the same T_{ct} between 1950 and 1999. Similarly, technological investment by motorized vessels were restricted

between 1950 and 1979 due to fishers' limited purchasing power (Caravedo, 1979; Miranda, 2016). Nonetheless, the amount and size of the fishing gear carried by motorized vessels (e.g., the length and number of longlines) started to increase across métiers between 1980 and 1999, with mechanized winches becoming more commonly used by small-scale purse seiners (Sueiro and De la Puente, 2015). Additionally, increases in the use and area of coverage of cellphones led to a faster technological creep across all métiers between 2000 and 2018, and particularly in the last decade. However, the much faster creep experienced by vessels using longlines or squid jigs reflects their investments for improving hold insulation and gaining access to sounders and GPS navigators (INEI, 2012; Marín et al., 2017; Castillo et al., 2018).

Estimating Fishing Effort at Different Scales

Effective and nominal fishing effort time series were estimated for each métier (Eqs. 1–2). The number of days spent at sea per year (D_t), used for these computation were approximated from published literature (Table 3; Alfaro-Shigueto et al., 2010; Estrella and Swartzman, 2010; Sueiro and De la Puente, 2015; Marín et al., 2017), and were consistent with those used in global studies (Anticamara et al., 2011). Annual effort estimates were added across all métiers using the same fishing method to compute nE_t and E_t at the sub-fleet level, and across all sub-fleets to estimate the small-scale fleet's total fishing effort. The units for fishing effort are $\text{kW} \cdot \text{days}$ (Belhabib et al., 2018).

Estimating Catch per Unit of Effort

Catches were divided by nominal and effective fishing effort to produce time series of nominal and effective catch per unit of effort with annual time steps ($nCPUE_t$ and $CPUE_t$, respectively). $nCPUE_t$ and $CPUE_t$ were estimated for each sub-fleet and for the total small-scale fleet. The units for these indicators are expressed in $\text{kg} \cdot \text{kW}^{-1} \cdot \text{days}^{-1}$. Catch data used in these calculations was extracted from the *Sea Around Us* database.¹

Peruvian catch data included in the *Sea Around Us* database was reconstructed for the period between 1950 and 2018 using the methods described in Mendo and Wosnitza-Mendo (2014). The starting point of the reconstruction process is data reported by FAO. These are considered 'nominal catches' that are corrected, using ancillary sources of information, so that the 'total reconstructed catch' incorporates previously unreported data (e.g., discards and IUU fishing) (Zeller and Pauly, 2016).

¹www.seaaroundus.org

TABLE 2 | Annual rates of increase in relative technological power assumed to have been experienced by different métiers in the Peruvian small-scale fleet over time.

Period	Non-motorized vessels (% · year ⁻¹)	Motorized vessels using hands or tools, handlines, gillnets, traps, or trawl nets (% · year ⁻¹)	Motorized vessels using longlines or squid jigs (% · year ⁻¹)	Motorized vessels using purse seine nets (% · year ⁻¹)
1950–1979	1.0	1.0	1.0	1.0
1980–1989	1.0	1.5	1.5	2.0
1990–1999	1.0	1.5	1.5	2.0
2000–2009	2.0	2.0	3.0	2.5
2010–2018	2.0	2.5	3.5	3.0

TABLE 3 | Additional parameters used to estimate small-scale fishing effort and fishers' incomes, segregated by fishing method.

Fishing method	Days spent fishing (year ⁻¹)	Crew size (number of fishers)	Fishers' income as a percentage of vessel revenue (%)
Gillnets	200	1–4	50
Handlines	250	1–3	60
Hands or tools (divers)	180	3–5	40
Longlines	290	4–6	40
Purse seine nets	190	5–8	35
Squid jigs	270	4–7	29
Traps	120	3–6	30
Trawl nets	180	5–7	10

For more detailed information on the sources of data used in the Peruvian catch reconstruction, see **Supplementary Material**.

Catches corresponding to the artisanal sector of Peru (i.e., small-scale fisheries) were extracted from the total reconstructed catch, which also includes catches corresponding to the industrial, recreational and subsistence sectors (Mendo and Wosnitza-Mendo, 2014). The artisanal catch was then distributed among fishing gears following the methods described by Cashion et al. (2018). Data on species catches by gear was available for some years of the time series (e.g., 1986–1988, Wosnitza-Mendo et al., 1988; 1996–2012, Marín et al., 2017). These were used as anchor points. The proportion of the catch caught by a given fishing method was estimated for all taxa in years when data was available. These proportions were used together with fishing effort estimates, by sub-fleet responsible for a taxon's annual catch, to determine taxon-specific gear preferences. These were used to infer the distribution of the catch among fishing methods, using fishing effort, for years lacking catch by gear by species data. Confidence intervals for the reconstructed catch data were estimated following the methods described in Zeller and Pauly (2016).

Assessing the Socio-Economic Consequences of Changes in Small-Scale Fishing Effort

The value of the small-scale catch (R_t) was estimated using official off-vessel price data for the Peruvian small-scale fleet produced by the Instituto del Mar del Perú² and the reconstructed catch data retrieved from the *Sea Around Us* database. Given the shorter length of the off-vessel price time series, R_t was only estimated for the 2009–2018 period. Price data, originally expressed in Peruvian 'Nuevos Soles,' was converted to United States Dollars using the official exchange rate and then corrected for inflation by dividing it by the Consumer Price Index (IPC, acronym in Spanish) for food items. The official exchange rates and IPC were extracted from the Central Reserve Bank of Peru (BCRP, acronym in Spanish) online databases.³ The value of R_t was estimated for each sub-fleet and

for the whole small-scale fleet and is expressed in real 2009 USD · year⁻¹.

Two indicators were used to assess the socio-economic impact of changes in fishing effort on small-scale fishers: (a) the revenue per unit of effort ($RPUE_t$), computed by dividing R_t by E_t , serving as a proxy for the economic efficiency of the fleet and sub-fleets; and (b) fishers annual incomes relative to minimum wage (rI). The value of rI was computed for each sub-fleet such that:

$$rI_{jt} = R_{jt} \times p_j / n_{jt} \times CS_j \quad (3)$$

Where: rI_{jt} is the average fishers income using fishing method j in year t , p_j is a constant representing the proportion of the vessel's revenue allocated to paying fishers' salaries [retrieved from Christensen et al. (2014) and Sueiro and De la Puente (2015)], n_{jt} is the number of vessels in the sub-fleet, and CS_j is the typical crew size per vessel within the sub-fleet (Estrella and Swartzman, 2010; Sueiro and De la Puente, 2015; Marín et al., 2017). Values for p_j and CS_j are included in **Table 3**. If rI_{jt} falls below the minimum wage (i.e., $rI_{jt} < 1$), it can be assumed that fishers are unable meet the minimum level of living standards compared to other Peruvians and are thus living in 'relative poverty' (Hagenaars and van Praag, 1985).

Assessing Performance Indicators Over Time

Significant breakpoints in nE_t , E_t , $nCPUE_t$, and $CPUE_t$ time series, reflecting changes in trends (i.e., slope) over time, were identified by analyzing the time series trajectories for these parameters using segmented regression (Muggeo, 2003, 2008). The significance of linear trends in $RPUE_t$ within the 2009–2018 period, were assessed using simple regression analysis. All analyses and figures were done in R (Ver. 3.6.3).

RESULTS

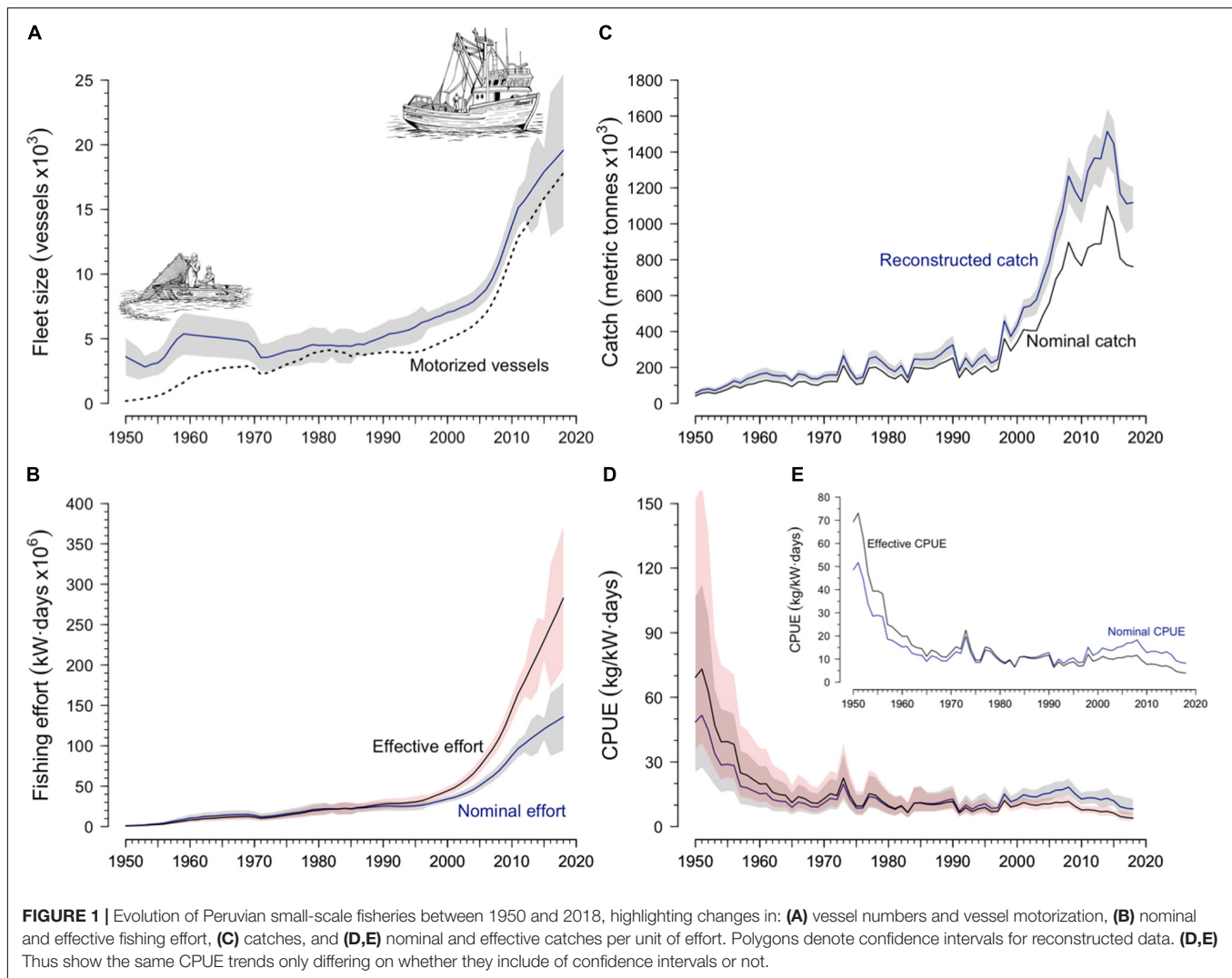
A Growing Small-Scale Fishery

The Peruvian small-scale fleet has strongly increased in size over the last seven decades (**Figure 1A**). In 2018, fleet size was estimated to be 5.4 times larger than in 1950. Growth rates, however, were not constant over the years. The fleet grew at a 'moderate' rate of 220 vessels · year⁻¹ between 1950 and 1961, but decreased almost as fast between 1962 and 1971 (–180 vessels · year⁻¹). Growth was limited between 1972 and 1990 (70 vessels · year⁻¹). However, the fleet then started to grow much faster (i.e., 1991–2005: 220 vessels · year⁻¹), and grew fastest between 2006 and 2010 (1,390 vessels · year⁻¹). Although growth rates more than halved since, the fleet still grew by 640 vessels · year⁻¹ from 2011 to 2018.

Additionally, vessel motorization increased substantially, from 5% in 1950 to 91% in 2018 (**Figure 1A**). The number of new engine-powered vessels entering the fleet or existing boat being fitted with engines, grew steadily across the time series, except for the period between 1982 and 1996. During these 15 years of

² www.imarpe.gob.pe

³ www.bcrp.gob.pe



limited growth in total fleet size, a relatively large number of non-motorized vessels entered the fleet. Nonetheless, since 1997 the temporary reduction in vessel motorization was overturned.

Moreover, the composition of the fleet by length class also changed in favor of larger vessels. For example, only 2% of the fleet was composed of motorized vessels with total lengths larger than 10 m (VT4) between 1950 and 1969; this type of vessels represented 20% of the fleet between 2000 and 2018.

The reported increases in fleet size, vessel motorization and vessels' total length have contributed to strongly increasing nominal and effective fishing effort (nE_t and E_t , respectively) across the studied period (**Figure 1B**). Fishing effort grew fastest after the turn of the century, and more so if the technological creep was also considered (e.g., nE_t was four times larger in 2018 than in 2000; E_t was two times larger than nE_t in 2018, but only 30% larger than it in 2000).

As expected, increases in fishing effort resulted in greater catches, at least for part of the time series (**Figure 1C**). Reconstructed catches, accounting for the unreported landings and discards, were on average 33% ($\pm 2\%$) larger

than the reported landings (i.e., nominal catch) over time. Growth in catches was moderate between 1965 and 1996 ($3,761 \text{ tons} \cdot \text{year}^{-1}$), and much faster between 1997 and 2014 ($74,237 \text{ tons} \cdot \text{year}^{-1}$). Catches surpassed the million tons mark in 2007 and have not fallen below this mark since. However, after reaching their peak value in 2014, reconstructed catches exhibit a rapidly declining trend.

For more information regarding: (i) the evolution of the fleet by vessel type, (ii) changes in nE_t and E_t over time by fishing method, (ii) statistically significant breakpoints in effort trends, and (iii) changes in their slopes, see **Supplementary Material**.

Declining Fishing Efficiency

Nominal and effective catches per unit of effort ($nCPUE_t$ and $CPUE_t$, respectively) significantly declined over time (**Figure 1D**). Breakpoints and changes in slope were consistent between both indicators (**Figure 1E**). For information regarding $nCPUE_t$ trajectories, see **Supplementary Material**.

Overall $CPUE_t$ declined until the early 1990s, decreasing fastest at the start of the time series (1950–1959) and at slower

rates since 1960. In 1993 the trend reversed, and until 2006 $CPUE_t$ increased at slow annual rates. In 2007 the trend again reversed itself, with $CPUE_t$ declining until the end of the time series (Table 4).

The trend in $CPUE_t$ experienced by the small-scale fleet was not shared by all sub-fleets (Figure 2 and Table 4). Vessels using gillnets, handlines and purse seine nets show consistent

TABLE 4 | Summary indicators of the segmented regression analysis of effective Catch per unit of Effort ($CPUE_t$) time series.

Fishing methods	Breakpoints ($\pm SE$) [†]	Slope ($\pm SE$) [‡]	p-value [§]	Adjusted R ²
Gillnets	1950 (± 0)	-9.32 (± 0.45)	4.55E-29*	0.9734
	1958.33 (± 0.33)	-0.85 (± 0.47)	4.98E-26*	
	1979.91 (± 2.03)	0.31 (± 0.25)	1.35E-05*	
	1994.02 (± 3.21)	-0.40 (± 0.23)	3.58E-03*	
Handlines	1950 (± 0)	-2.61 (± 1.18)	3.06E-02*	0.6582
	1954 (± 1.96)	-0.75 (± 1.25)	1.41E-01	
	1961.99 (± 2.81)	0.03 (± 0.41)	5.89E-02	
	2000.99 (± 3.07)	-0.45 (± 0.13)	3.18E-04*	
Hands or tools (Divers)	1950 (± 0)	0.84 (± 0.31)	9.15E-03*	0.8636
	1967 (± 1.36)	4.43 (± 0.76)	1.40E-05*	
	1976.22 (± 0.68)	-2.84 (± 0.76)	9.63E-14*	
	1993.07 (± 1.54)	-0.29 (± 0.36)	1.37E-09*	
Longlines	1950 (± 0)	-20.28 (± 1.46)	1.43E-20*	0.9609
	1951.15 (± 0.07)	-1.05 (± 1.46)	1.99E-19*	
	1960.19 (± 0.82)	-0.12 (± 0.13)	3.90E-09*	
	1990.92 (± 2.53)	0.09 (± 0.03)	1.17E-08*	
	1950 (± 0)	-26.66 (± 2.02)	1.50E-19*	
Purse seine nets	1955.44 (± 0.28)	-0.55 (± 2.02)	4.02E-19*	0.9308
	2005.62 (± 2.39)	4.59 (± 11.94)	6.68E-01	
	2007.09 (± 2.09)	-0.50 (± 11.96)	6.72E-01	
Squid jigs	1990 (± 0)	-0.88 (± 0.38)	3.08E-02*	0.9536
	1997.89 (± 0.28)	9.49 (± 1.16)	1.42E-08*	
	2002 (± 0.27)	-3.17 (± 1.16)	4.37E-10*	
	2010 (± 1.15)	-1.04 (± 0.5)	3.13E-04*	
Traps	1950 (± 0)	0.02 (± 0.02)	2.98E-01	0.7594
	1986.63 (± 1.87)	0.47 (± 0.06)	6.99E-06*	
	2006.42 (± 0.87)	-2.55 (± 2.15)	4.86E-05*	
	2008.11 (± 0.69)	0.31 (± 2.15)	6.35E-01	
Trawl nets	1970 (± 0)	-20.17 (± 2)	1.50E-12*	0.8877
	1978.55 (± 0.55)	1.64 (± 2.27)	6.34E-12*	
	1990 (± 2.6)	-2.70 (± 1.79)	1.99E-02*	
	2000.22 (± 3.43)	0.23 (± 1.54)	6.48E-02	
All methods	1950 (± 0)	-6.38 (± 0.36)	1.87E-25*	0.9596
	1958.56 (± 0.35)	-0.27 (± 0.37)	2.62E-24*	
	1993.07 (± 3.56)	0.26 (± 0.21)	1.58E-02*	
	2006.47 (± 2.47)	-0.66 (± 0.32)	5.01E-03*	

[†]'Breakpoints' reflect changes in the slope of the regression (in years). [‡]'Slope' is the rate of change in $CPUE_t$ between breakpoints. The 'p-values' reflect the statistical significance of the regression, whilst the 'Adjusted R²' reflects the proportion of the variation in slope explained by the regression. Breakpoints and slopes are presented next to their respective standard errors (SE). [†]Units in years. [‡]Units in (kg/kW · days) · year⁻¹. [§]Statistically significant p-values ($p < 0.05$) are indicated with an asterisk (*).

declines in $CPUE_t$, with steep declines in the first decades and much gentler declines since. As with the previous group, vessels fishing with longlines show declines in $CPUE_t$ at the beginning of the studied period and later (early 1990s) reverse the trend with faint increases in $CPUE_t$. Contrary to this trend is that shown by vessels using hands or tools (i.e., divers) and traps, whose $CPUE_t$ trajectories start with positive slopes, followed by declining trends. Finally, vessels using trawl nets and squid jigs show two trend reversals in their $CPUE_t$ trajectories. They, start with negative slopes, followed by a relatively short period where $CPUE_t$ increases and then by a second period of declining $CPUE_t$.

Moreover, fishing efficiency differed substantially across small-scale fishing methods. When comparing sub-fleets' average $CPUE_t$ between 2009 and 2018, three groups emerge: sub-fleets using gillnets (1.7 ± 0.1 kg · kW⁻¹ · days⁻¹ · year⁻²), handlines (1.7 ± 0.2 kg · kW⁻¹ · days⁻¹ · year⁻²), and longlines (2.5 ± 0.2 kg · kW⁻¹ · days⁻¹ · year⁻²) have relatively low fishing efficiency; sub-fleets using traps (4.4 ± 0.3 kg · kW⁻¹ · days⁻¹ · year⁻²) and hands or tools (4.8 ± 0.5 kg · kW⁻¹ · days⁻¹ · year⁻²) are moderately efficient; and finally, vessels using squid jigs (9.5 ± 0.7 kg · kW⁻¹ · days⁻¹ · year⁻²), trawl nets (11 ± 0.8 kg · kW⁻¹ · days⁻¹ · year⁻²), and purse seine nets (13.1 ± 0.4 kg · kW⁻¹ · days⁻¹ · year⁻²) are the most efficient.

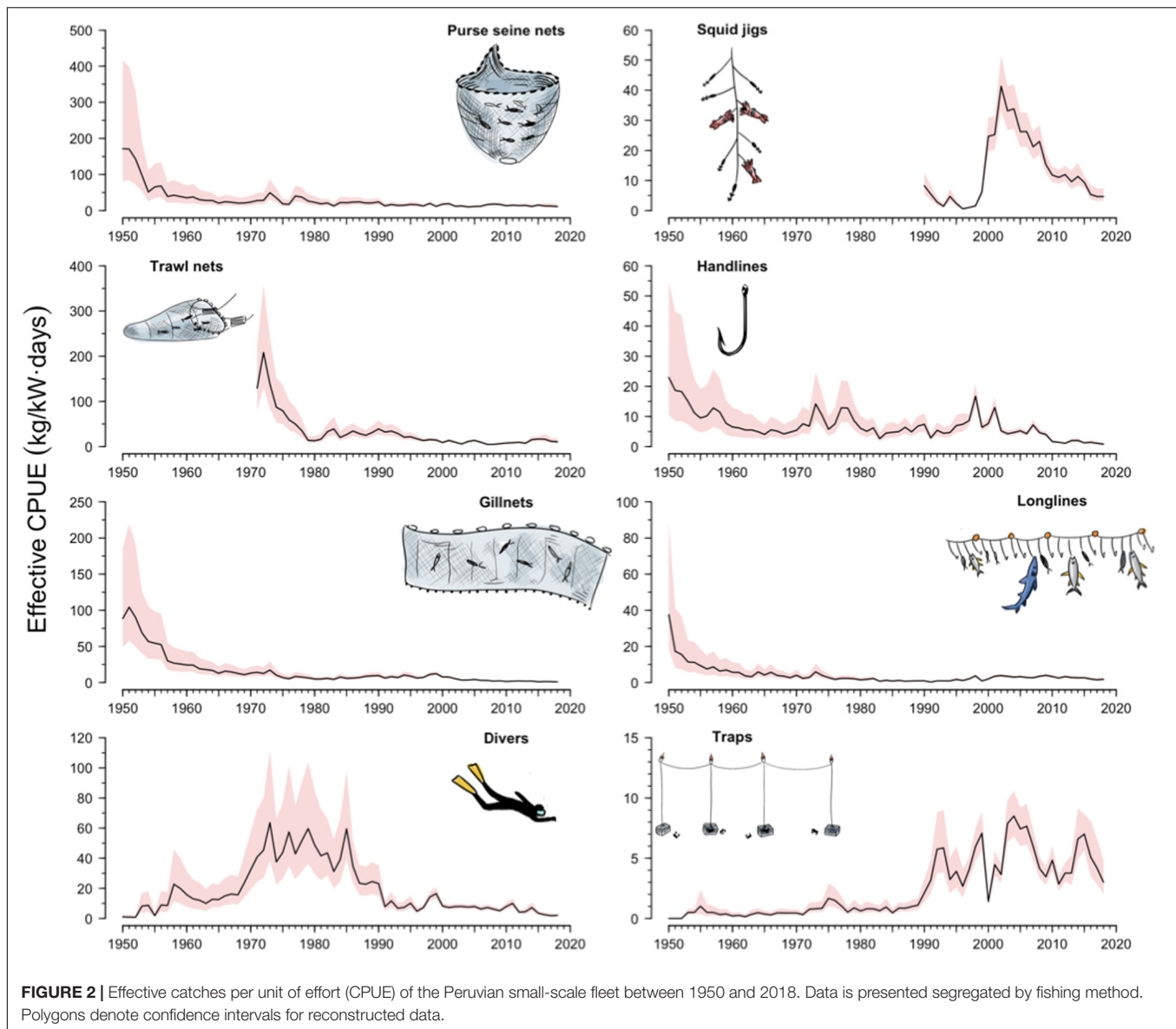
Uneven Economic Performance Within the Small-Scale Fleet

Changes in the economic performance of the small-scale fleet depends on: (1) the annual catch, (2) the species composition of the catch, (2) the prices of landed items, (3) the percentage of the sub-fleets' revenue used for paying fishers salaries (Christensen et al., 2014), and in this case, the Peruvian minimum wage as well.

Catches by sub-fleet were quite stable between 2009 and 2018, except for vessels using trawl nets, whose catch grew significantly ($p = 0.005$) over the decade at an average rate of 3,995 tons · year⁻¹. Vessels using squid jigs and purse seine nets, were responsible for most of the small-scale catch during this period (42 and 36%, respectively), whilst sub-fleets using longlines (7%), hands or tools (5%), gillnets (5%), trawl nets (2%), handlines (2%), and traps (1%) were minor contributors in comparison.

However, things are different in terms of revenue. Small-scale fisheries directly generated a total annual average revenue of \$902 million · year⁻¹ ($\pm \49 million · year⁻¹) between 2009 and 2018. Vessels equipped with purse seines were responsible for 34% of the total small-scale revenue over the decade, followed by those using squid jigs (17%), longlines (13%), hands or tools (12%), trawl nets (11%), and gillnets (9%). As with total catches, vessels fishing with handlines (3%) and traps (1%) were only minor contributors to the fleet's total revenue.

As expected, due to the observed $CPUE_t$ trajectory, the fleet's $RPUE_t$ significantly declined between 2009 and 2018 ($p = 0.0054$) (Figure 3). $RPUE_t$ declines were also significant for vessels using longlines ($p = 0.0001$), divers (hands or tools; $p = 0.004$), gillnets ($p = 0.0055$), and handlines ($p = 0.008$), but not for those fishing with purse seine nets, squid jigs and traps, whose $RPUE_t$ was



relatively stable, nor for vessels using trawl nets, whose increase in $RPUE_t$ was almost statistically significant.

These trends affect small-scale fishers' wellbeing in an uneven manner. Looking at their annual incomes relative to Peru's minimum wage (rI) reveals an alarming scenario (Table 5). Fishers of only two sub-fleets are doing well. Trawl fishers' rI has increased since 2013, being over 6 times larger than Peru's minimum wage in 2017 and 2018; while rI for fishers using purse seine nets has been consistently above the minimum wage (roughly 2 times as large) throughout the decade. However, all other small-scale fishers' relative incomes show reductions over time. Annual earnings by trap fishers, fell below the minimum wage for 9 years within the decade. Squid jiggers' rI were smaller than the minimum wage between 2012–2013 and 2015–2016. Handliners' and gillnetters' rI have been consistently below the minimum

wage since 2015. Finally, longliners' rI , although showing a 60% decline over the last decade, never went below the minimum wage.

For more information on the catch by sub-fleet and off-vessel prices by target resource, in real US dollars, see **Supplementary Material**.

DISCUSSION

Growing Into Poverty Unsustainable Fleet Growth

Peruvian small-scale fisheries are experiencing a dangerous and resilient pathology where uncontrolled fleet growth is directly reducing fishing efficiency and fishers' wellbeing. This growth in fishing effort is unsustainable (Pauly, 2009). It is important

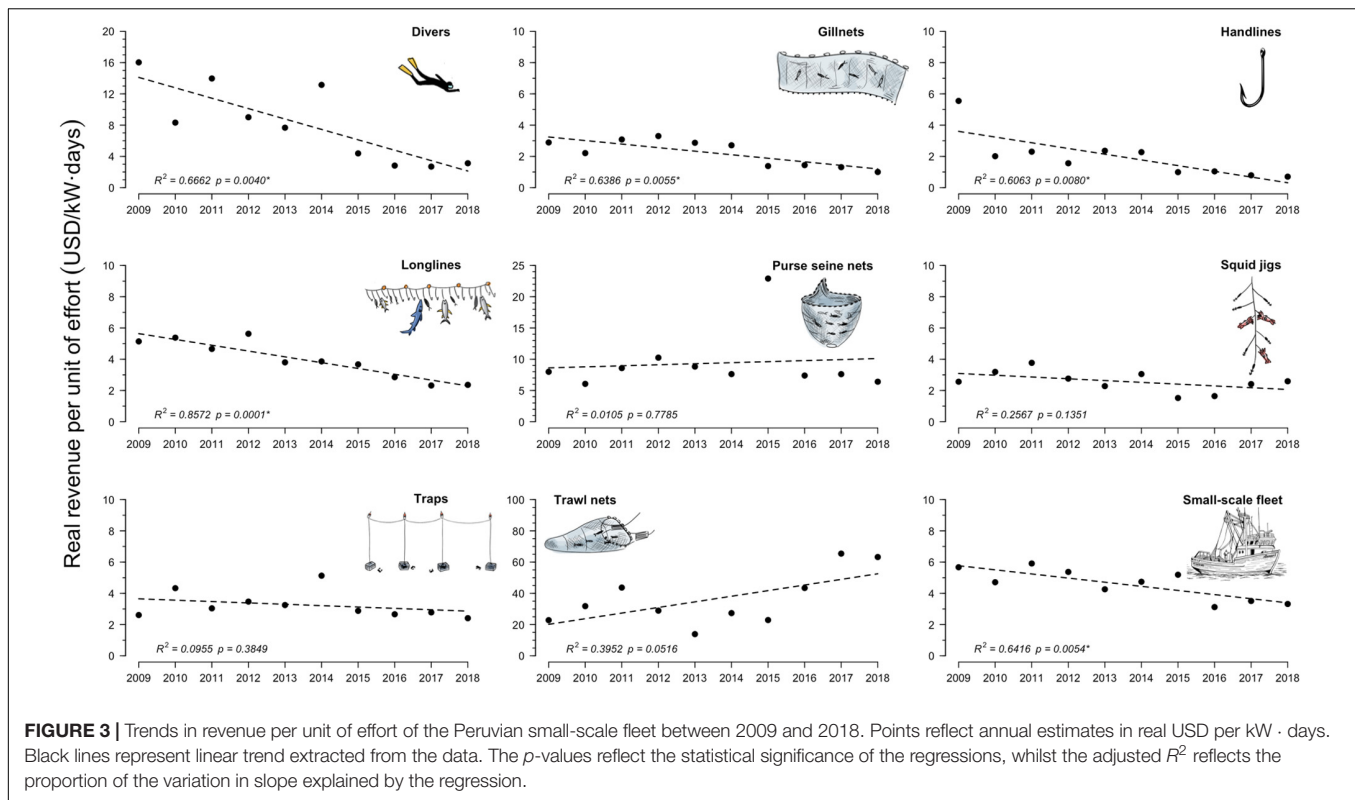


TABLE 5 | Small-scale fishers' annual average incomes relative to the Peruvian minimum wage.

Fishing methods	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Gillnets	1.76	1.16	1.43	1.26	1.21	1.22	0.73	0.72	0.65	0.49
Handlines	1.68	0.96	1.19	0.72	1.20	1.23	0.64	0.65	0.50	0.44
Hands or tools (Divers)	7.08	3.18	4.79	2.53	2.34	4.24	1.66	1.01	0.95	1.08
Longlines	3.59	3.24	2.52	2.51	1.88	2.02	2.27	1.68	1.36	1.38
Purse seine nets	2.99	1.87	2.25	2.22	2.12	1.97	6.89	2.10	2.17	1.83
Squid jigs	1.42	1.53	1.61	0.98	0.92	1.31	0.78	0.80	1.17	1.25
Traps	0.71	1.01	0.62	0.59	0.60	0.98	0.65	0.55	0.58	0.50
Trawl nets	2.96	3.47	4.19	2.26	1.22	2.52	2.45	4.39	6.53	6.25
Peruvian annual minimum wage (in real 2009 USD)	2064	2460	2832	3540	3300	3216	2820	3060	3180	3300

Relative incomes below the minimum wage are highlighted in red.

to clarify that we do not claim that all stocks targeted by the small-scale fleet are overexploited, but rather that current effort levels are excessive for catches to be sustained, let alone to enable a recovery of overexploited stocks. This assertion is supported by the declining trajectory of the effective catch per unit of effort ($CPUE_t$) observed across the time series (Figure 1). It showcases that more effort is now required to capture the same amount of fish over time, and hence that less marine living resources are currently available for the growing fleet. A scenario that is further warranted by: (i) the expanding fishing grounds of the fleet (Marín et al., 2017), and (ii) the reduced importance of traditional target species in the catch (Mendo and Wosnitza-Mendo, 2014).

There are several caveats to the use of ratio estimators (e.g., catch per unit of effort) as indicators of relative abundance for

targeted stocks. For example, catches can decline in areas that are not representative of the stock's overall distribution, and if only focused on these, declines in CPUE would be unrealistically rapid and unrepresentative of the stock's abundance. This phenomenon is known as hyperdepletion (Walters, 2003).

However, our analysis is not focused on individual stocks. The Peruvian small-scale fleet is part of a multi-species fishery: (i) where most boats target coastal resources but whose fishing area keeps expanding further offshore (Estrella and Swartzman, 2010; Marín et al., 2017), (ii) which lacks effective input and output (SPDA, 2019), (iii) in which most fishers have decades (Castillo et al., 2018) and a vast understanding of the temporal and spatial distribution of resources, i.e., productive fishing areas (Sueiro and De la Puente, 2015). Technological improvements and fishers' growing experience should be increasing the fleet's catchability

(Palomares and Pauly, 2019). Additionally, the fleet's expansion into previously unfished areas should be generating increasing catches if resource abundance within them were high (Hilborn and Walters, 1992). Thus, by pooling together all small-scale catch and effort data within the Peruvian EEZ we should expect the converse of hyperdepletion, i.e., hyperstability in $CPUE_t$. Yet we observe a declining $CPUE_t$ trajectory, and declining catches as well (Figure 1).

Nonetheless, statistically significant increases in both fleets' $CPUE_t$ and E_t were registered between 1993 and 2006 (Table 4). These favorable conditions can perhaps be explained by the combined effect of: (i) a change in primary productivity and oceanographic conditions (e.g., a regime shift), potentially increasing the carrying capacity for multiple traditionally targeted coastal stocks (Ayón et al., 2011; Bertrand et al., 2011; Salvatelli et al., 2019); (ii) a segment of the fleet starting to venture further offshore (i.e., small-scale squid jiggers and longliners) targeting non-traditional, more abundant, stocks such as jumbo squid (*Dosidicus gigas*), mahi-mahi (*Coryphaena hippurus*), and pelagic oceanic sharks (e.g., *Prionace glauca*, *Isurus oxyrinchus*, and *Alopias vulpinus*) (Estrella and Swartzman, 2010; Mendo and Wosnitza-Mendo, 2014; Marín et al., 2017); and (iii) the implementation of Decreto Supremo No. 017-92-PE, a fisheries regulation that excludes industrial purse seiners and trawlers from the first five nautical miles off the coast, seeking to reduce industrial bycatch and habitat damage in areas known to be important for traditional small-scale fishery resources (SPDA, 2019).

However, fishing effort started growing at faster rates with the turn of the century, and much faster than the catch by 2006 (Figure 1 and Table 4). This caused a trend reversal in the fleet's $CPUE_t$ trajectory, showing that fishing effort was indeed too high, and that the overall surplus production of targeted stocks was declining (Froese et al., 2019).

This explanation is consistent with the $CPUE_t$ trajectories of vessels using gillnets, handlines, hands or tools, and purse seine nets (Figure 2 and Table 4). These sub-fleets make up most of the small-scale fleet and target coastal resources (Marín et al., 2017; Castillo et al., 2018), some of which already show signs of overfishing (CEDEPESCA, 2013; Sueiro and De la Puente, 2015). Conversely, sub-fleets using traps and trawl nets also target coastal resources but show positive, although not statistically significant, trends in $CPUE_t$ over the last decade (Figure 2 and Table 4). These trajectories must be taken with caution, but potentially hint to: (i) the recovery of the punctuated snake-eel (*Ophichthus remiger*), the main species targeted by vessels using traps, after the recent implementation of a rebuilding plan that included input and output controls; and (ii) important increases in the catch of penaeid shrimps by trawl nets, mediated by favorable environmental conditions (IMARPE, 2018).

Sub-fleets whose catch was mostly composed of oceanic resources show mixed trends in $CPUE_t$ over the last two decades (i.e., longlines and squid jigs; Figure 2 and Table 4). However, it is more likely that changes in their $CPUE_t$ are driven by environmental factors modifying their catchability (e.g., by changing the density of targeted schools or the distances at which they are found relative to the shores), rather

than suggesting changes in the relative abundance and status of targeted species (Flores et al., 2016; Csirke et al., 2018; Torrejón-Magallanes et al., 2019).

Uneconomic Growth

It is important to also consider socio-economic indicators to define overfishing (Hilborn et al., 2015). We used three indicators of this sort to assess the small-scale fleet behavior, and after looking at their performance over the last 10 years, we claim that recent increases in fishing effort were not only unsustainable but also uneconomic (Daly, 2005). This assertion is supported by the declining trajectories of the small-scale fleet's revenue per unit of effort ($RPUE_t$) (Figure 3) and the fishers' relative income to the minimum wage (rI) (Table 5), albeit the fleet's total revenue (R_t) remaining stable over the last decade. As vessel owners subtract the operating costs of fishing from R_t before paying salaries to the crew (Sueiro and De la Puente, 2015), it is likely that they are better at withstanding the negative consequences of declining $RPUE_t$.

Significant decreases in $RPUE_t$ were observed for vessels using gillnets, handlines, hands or tools and longlines (Figure 3), even when the last of the gears showed a growing $CPUE_t$ trajectory over the same period (Table 4). This indicates that the marginal utility of capital investments (i.e., new vessels) was decreasing and furthering economic inefficiency (Daly, 2005, 2013). Nonetheless, declining trajectories in $RPUE_t$ were not observed across all sub-fleets (Figure 3). For vessels fishing with squid jigs, price elasticity kept $RPUE_t$ stable, as the unsatisfied demand for jumbo squid by local frozen seafood processing plants (Christensen et al., 2014) resulted in much higher off-prices when catches started to decline (see Supplementary Material). Moderate declines in E_t kept $RPUE_t$ stable for the trap sub-fleet, even with highly variable catches. Changes in the catch composition of small-scale trawlers in favor of highly valuable shrimp species, combined with greater landings, prevented declines in $RPUE_t$ albeit significant increases in E_t (see Supplementary Material). Finally, the economic contribution of illegal landings of anchoveta by small-scale purse seiners (Guardiola et al., 2012; Grillo et al., 2018), kept them profitable despite increases in E_t , which stabilized their $RPUE_t$ over the last decade (Figure 3). This sub-fleet would be significantly less profitable, however, if fisheries regulations were adequately enforced (Sueiro and De la Puente, 2015).

Although the Peruvian small-scale fleet has been able to withstand declines in $CPUE$ and remain profitable in the past (Alfaro-Shigueto et al., 2010), this does not mean that such declines have not taken their toll on fishers' wellbeing. As shown in this study, most sub-fleets' rI has declined significantly over the last decade and many of fishers are already living in relative poverty (Hagenaars and van Praag, 1985). At first, this finding might come across as strange given that recent national surveys indicate that small-scale fishers' incomes have increased since 2012 (Marín et al., 2017; Castillo et al., 2018). However, after correcting for inflation, fishers' incomes and their trajectories over time are consistent with those estimated here. For example, in 2015 people living on the Peruvian minimum wage generated an annual income of real 2009 USD 2,820. During that year, 31% of surveyed small-scale fishers

reported annual incomes below \$1500, while 39% reported annual incomes between \$1500 and \$3000 (Castillo et al., 2018). Coincidentally, we found that fishers using gillnets, handlines, squid jigs and traps, which represent ~65% of small-scale fishers working in 2015, earned less than the minimum wage that year (Table 5).

It is worth noting that the only fishers who did not experience declining *RI* were using small-scale purse seine and trawl nets. This is problematic as it reveals that incomes could be kept relatively stable, at least for a while, by using the least selective and most ecological damaging fishing methods (Chuenpagdee et al., 2003; Salazar Céspedes, 2019).

The Usual and the Unusual Suspects

Small-scale fishers are a globally vulnerable and marginalized population (Pauly, 2006) whose ability to withstand environmental or economic shocks is curtailed by their limited human capital and economic assets (Finkbeiner et al., 2017; Chuenpagdee and Jentoft, 2019). Their struggles are not evident to others outside the fisheries, including seafood users along the value chain, as markets and social traps distort and muffle them (Salas et al., 2007; Crona et al., 2016a,b). Yet, what are the root causes of the explosive increase in small-scale fishing effort observed in Peru?

As seen in other developing countries, small-scale fisheries tend to absorb a large contingent of the unemployed population migrating to the coasts (Pauly, 2006). In Peru this process started in late 1980s as internal conflicts and terrorism displaced a significant part of the national population from the Andes and Amazon to the coast (Sueiro and López de la Lama, 2014; Sueiro and De la Puente, 2015).

Nonetheless, it is likely that legal changes have had more pervasive impacts than migration. In 1992, a new General Fisheries Law came into effect (Decreto Ley 25977). Through it the government sought to foster the development of the small-scale fleet, and thus waived for them a key administrative requirement for constructing new vessels: the “authorization to increase the fleet size” (in Spanish: ‘autorización de incremento de flota’). This allowed for the construction of small-scale vessels without government oversight or fishing licenses. Later, in 1998, the Ministry of Fisheries (now Ministry of Production or PRODUCE) further relaxed regulations to soften the negative economic impacts of the 1997/1998 El Niño event on small-scale fishers, by changing the nature of their fishing licenses from ‘single species’ to ‘multi-species’ (Resolución Ministerial 593-98-PE). This modification granted them access to catch all marine living resources if destined for human consumption.

Furthermore, Peru started a process of decentralization in 2002 (Ley 27867), transferring power from the central government to the regional governments (‘GOREs’). By 2004, PRODUCE began delegating competences regarding small-scale fisheries monitoring and enforcement to the regions. However, many GOREs did not have the capacities (e.g., training, manpower, or budgets) required for such undertaking, resulting in the weakening of the rule of law (Sueiro and De la Puente, 2015; Monteferri et al., 2017). Although many GOREs have

overcome multiple shortcomings (SPDA, 2019), their fisheries-related budgets remain low and insufficient for the tasks at hand (Pajuelo and Sueiro, 2019).

By 2006, PRODUCE sought to curtail the rapidly growing small-scale fleet. First by suspending the construction of new vessels whose hull capacity exceeded 10 m³ (Decreto Supremo 020-2006-PRODUCE; Decreto Supremo 018-2008-PRODUCE; Decreto Supremo 015-2010-PRODUCE). As smaller boats started to enter the fleet, this suspension was extended to vessels whose holding capacity ranged between 5 and 10 m³ in 2010 (Decreto Supremo 018-2010-PRODUCE). As the fleet continued to increase, by 2012 PRODUCE prohibited the construction of new small-scale vessels regardless of their size (Decreto Supremo 005-2012-PRODUCE). This prohibition is still in effect (Decreto Supremo 006-2015-PRODUCE), yet the fleet continues to increase.

A factor limiting enforcement for these bans comes from the bylaws specifying fisheries infractions and penalties (Decreto Supremo 016-2007-PRODUCE; Decreto Supremo 017-2017-PRODUCE). Although several regulations deem the construction of new small-scale vessels as illegal since 2006, the infraction is defined in these bylaws as: “constructing or importing fishing vessels without having an authorization to increase the fleet size; as well as modifying or rebuilding small-scale fishing vessels during periods of prohibition or suspension.” The wording of this infraction is inadequate, as: (1) only new industrial vessels require authorizations for increasing fleet size, and (2) only small-scale vessel modifications and rebuilding are considered illegal. Thus, this infraction is inapplicable to new small-scale vessels entering the fleet, rendering the bans effectively unenforceable. Paradoxically, the associated penalty (fine) for this infraction is severe (Decreto Supremo 017-2017-PRODUCE).

An additional barrier halting compliance is the top-down governance approach implemented by the Peruvian government. Regulations directly impacting small-scale fishers are not generally drafted in an inclusive or participatory manner (Sueiro and De la Puente, 2015; SPDA, 2019). Hence, they lack legitimacy amongst fishers, who commonly misunderstand, oppose or disregard them albeit their potential benefits (Doherty et al., 2014; Nakandakari et al., 2017; López de la Lama et al., 2018; SPDA, 2019; Mason et al., 2020). Moreover, trust in governing authorities is poor, as they are often seen as inefficient and even corrupt (Sueiro and De la Puente, 2015; Nakandakari et al., 2017; López de la Lama et al., 2018), further incentivizing illegal behaviors (Salas et al., 2007; Finkbeiner et al., 2017). Also, and as seen in other developing countries, social capital is limited among some small-fishing communities further preventing them to find solutions to common problems through self-governance (Chuenpagdee and Jentoft, 2007; Salas et al., 2007; Nakandakari et al., 2017; López de la Lama et al., 2018).

Another dimension of this problem is economic. Battling poverty is a task that relentlessly occupies fishers’ attention. Many are so busy working to provide for their families, that coming to terms with the collective consequences (e.g., decreasing *RI*) of individual behaviors (e.g., commissioning a new vessel) becomes a challenge. This results in them blaming external factors, like industrial fisheries and pinniped conservation, for their current

circumstances (Sueiro and De la Puente, 2015); and reinforces their pursuit to improve their wellbeing by becoming vessel owners (i.e., increasing the small-scale fleet size).

Without disregarding the validity of fishers' claims, it is important to recognize that: (i) recent improvements in industrial fisheries management in Peru have reduced their bycatch and the impact of their catch on local marine ecosystems (Arias-Schreiber, 2012; De la Puente and López de la Lama, 2019), and (ii) pinnipeds have been seen as nefarious for fishers' economies and the status of their targeted stocks even when their abundance (and the size small-scale fleet) were both much smaller (Tovar and Fuentes, 1984).

Moreover, the last two decades have been periods of strong economic growth in Peru, leading to investments in the small-scale fleet by stakeholders whose primary sources of income are not necessarily fisheries dependent (Sueiro and De la Puente, 2015). This does not exclude industrial or small-scale fishers from purchasing small-scale vessels (Castillo et al., 2018). Yet, vessel ownership is somewhat concentrated and some boat owners are still able to profit (Christensen et al., 2014; Sueiro and De la Puente, 2015; Castillo et al., 2018). Thus, many small-scale fishers aspire to become vessels owners, but are increasingly having to supplement their incomes with seasonal jobs in agriculture or construction (INEI, 2012; Castillo et al., 2018).

The combined effect of these factors (i.e., internal migration, deficient regulations, top-down governance mechanisms, fishers' economic vulnerability and vessel ownership aspirations) has resulted in a *de facto* open access regime with strong perverse incentives for increasing small-scale fishing effort – which currently exceeds that of many other fishing countries around the world (Greer, 2014; Belhabib et al., 2018).

Limitations

This study has focused exclusively on assessing the performance of Peruvian small-scale fisheries that use vessels to capture marine living resources. Our findings are thus not representative of shore fishers (methods: beach seines, cast nets, handlines and traps; target group: coastal fishes), coastal gleaners (method: hands or tools; target group: invertebrates of the intertidal zone) and kelp collectors (method: hands or tools; target group: macroalgae). These groups of fishers do not use small-scale vessels and are minor contributors to the catch (INEI, 2012; Christensen et al., 2014; Marín et al., 2017).

Uncertainty exists in this analysis, mainly driven by the reconstruction methods for estimating catch data and inferring fishing effort between data anchor points. For more information on common sources of uncertainty in reconstructions and how they are dealt with please review: Mendo and Wosnitza-Mendo (2014) and Zeller and Pauly (2016). However, the results of this assessment resonate with findings by other researchers within the national and international context.

Nonetheless, it is important to mention that the declining trend in fishers' incomes may be underestimated. On one hand, a fixed cost-income structure (Christensen et al., 2014) was used for each métier between 2009 and 2018. Yet, vessel owners cover their cost (i.e., deduce all operating cost from the revenue) before paying their crews (Sueiro and De la Puente, 2015). Thus, increases in the fishing area covered by the fleet and changes

in fuel prices, could have led to reducing the aliquot of the revenue used to pay the crew. Furthermore, wages were assumed to be the same for all crew members within a small-scale fishing vessel. Nonetheless, skippers and motorists are known to have higher earnings than general crew members (Castillo et al., 2018). Hence, for some fishers the reported declines in their income might underrepresent their current financial struggles.

Thus, the authors ask readers to consider the results presented in this paper as a working hypothesis of the state of affairs in Peru. These findings can be used as a tool to communicate the dangers of continued fleet growth on local target resources and fishing communities. However, they should also be regarded as the starting point of a longer discussion, where if strengthened by additional and perhaps more accurate data, and then validated by local stakeholders, could be used as a tool to inform fisheries policy in Peru.

Recommendations

Although this section falls beyond the scope of this paper, we present some recommendations for the Peruvian government – rooted in robust social and fisheries science – aimed at improving small-scale fisher's wellbeing in Peru: (i) strengthen social capital within fishers' assemblies and fishing communities (Nakandakari et al., 2017; López de la Lama et al., 2018); (ii) increase fishers' involvement in research, as well as in the design, implementation and evaluation of fisheries policies and regulations (Punt et al., 2016; Chuenpagdee and Jentoft, 2019; McDonald et al., 2019); (iii) support successful, yet informal, self-governance arrangements currently in effect within fishing communities (Salas et al., 2007; Nakandakari et al., 2017; Chuenpagdee and Jentoft, 2019); (iv) reinforce local transdisciplinary research capacities aimed at improving and incorporating small-scale fisheries related knowledge into management (Pauly, 2006; Hilborn et al., 2015; Chuenpagdee and Jentoft, 2019); (v) promote investments for developing alternative sources of income within small-scale fishing communities (Sueiro and De la Puente, 2015); and (vi) enhance PRODUCE's and regional governments' enforcement capacities by increasing their budgets and modifying the legal tools at their disposal for discouraging illegal behaviors (Pajuelo and Sueiro, 2019; SPDA, 2019).

Conclusion

Small-scale fisheries, and their sustainable development, are highly important for Peruvian food security, economy and culture. However, small-scale fishing effort has significantly increased over time, negatively impacting target stocks, fishing efficiency and fishers' livelihoods. These findings are alarming and require immediate action, as small-scale fishers are a vulnerable population and growing into poverty could drive them further away from becoming resource stewards.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

SD conceptualized the study, analyzed and interpreted the data, and wrote the manuscript. SB reviewed and analyzed the Peruvian fisheries legal framework. RL, JS, and DP revised the manuscript. All authors approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2020.00681/full#supplementary-material>

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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