LETTER

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Catch shares slow the race to fish

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In fisheries, the tragedy of the commons manifests as a competitive race to fish that compresses fishing seasons, resulting in ecological damage, economic waste, and occupational hazards[1–8]. Catch shares are hypothesized to halt the race by securing each individual's right to a portion of the total catch, but there is evidence for this from selected examples only[2,9]. Here we systematically analyse natural experiments to test whether catch shares reduce racing in 39 US fisheries. We compare each fishery treated with catch shares to an individually matched control before and after the policy change. We estimate an average policy treatment effect in a pooled model and in a meta-analysis that combines separate estimates for each treatment–control pair. Consistent with the theory that market-based management ends the race to fish, we find strong evidence that catch shares extend fishing seasons. This evidence informs the current debate over expanding the use of market-based regulation to other fisheries.

In fisheries, the competitive race to fish compresses fishing seasons, with detrimental ecological and economic effects and increased occupational risks[1–8]. Traditional regulations that attempt to address the fisheries commons problem often backfire and exacerbate the competitive race[9,10]. Racing threatens fish stocks[1]; contributes to bycatch, discarding, and habitat disruption[1,2,5,11,12]; increases the cost of fishing[2,7]; decreases revenues by creating market gluts and steering product towards lower value uses[2,5,9,10]; and heightens safety risks because vessels are less able to avoid hazardous weather[13,14]. Catch shares are a type of market-based regulation in which individual fishermen, vessels, or cooperatives receive an allocation of the yearly total allowable catch (TAC). Securing each agent's share of the catch is hypothesized to end the race by allowing them to fish flexibly over time, maximize profits, and avoid hazards at sea. Here we report evidence that catch shares slow the race to fish by exploiting 39 natural experiments that compare control fisheries to fisheries treated with catch shares. Although many fisheries scientists and economists have argued that catch shares end the race to fish, this assertion rests on selected examples. Our results provide the first systematic evidence in support of this claim, to our knowledge. Over the past four decades, market-based approaches have been increasingly used to regulate environmental quality and natural resource use in fisheries, air and water quality, water resource use, greenhouse gas emissions, and hazardous waste[15]. We provide, to our knowledge, the first meta-analysis of economic outcomes from any type of market-based environmental regulation. Our results inform ongoing policy debate worldwide about market-based regulation in fisheries. The US Congress is currently considering competing draft bills to reauthorize the country's main fisheries management legislation: one would restrict the use of catch shares and the other would not.

The race to fish concentrates landings in a compressed season. Pre-existing regulations influence the extent of compression before catch shares. In some fisheries that do not use catch shares, a single season opening lasts until the entire annual TAC is caught, which leads to a short pulse of catches; for example, the Pacific halibut TACs for several Alaskan management areas have been caught in under five days[3,9]. In other fisheries (for example, Gulf of Mexico red snapper), regulators parcel out short season openings over the course of the year, spreading harvest somewhat but preserving incentives to race within each season opening[16]. Aggregate intra-seasonal harvest distributions illustrate fishing season compression and the possibility that catch shares reduce this compression (Fig. 1).

Despite broad scientific agreement and two recent empirical tests in individual fisheries[17,18], support for the hypothesis that catch shares end the race comes primarily from qualitative case studies and before–after comparisons[4,19–21]. Unfortunately, quantifying the change in fishing season length in these ways risks confounding correlation and causation. Other factors—for example, seafood markets, fishing technology, and fuel costs—affect season length[7,9], and changes in these factors may coincide with the introduction of a new policy. As a result, before–after comparisons fail to provide a valid counterfactual to assess the causal effect of the policy change.

By contrast, we adopt a treatment–control empirical strategy. Specifically, we use a quasi-experimental approach that matches each US fishery treated with catch shares to a control fishery that did not experience a change in treatment status (that is, management reform) at the same time, serves a similar market, and is prosecuted with similar technology. Matched fisheries control for confounding factors that coincided with the policy change. Because randomized controlled trials of catch share implementation are impractical, this counterfactual approach provides the most reliable empirical evidence available. By analysing differences before and after the policy change in multiple treated fisheries along with differences in the control fisheries during corresponding times, we isolate the effect of the policy change. Other

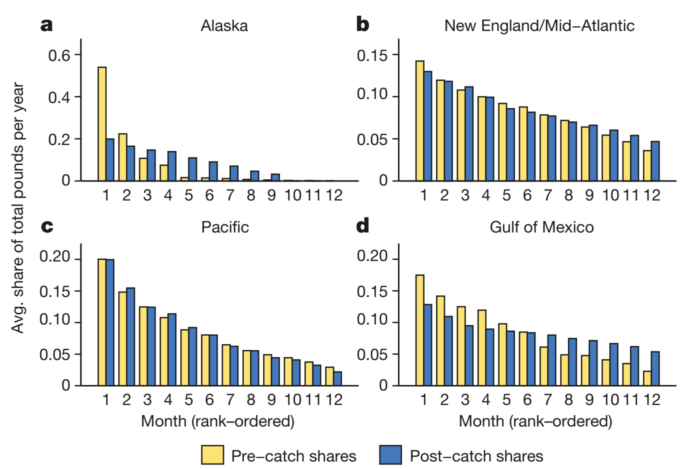

Figure 1 | Season compression before and after catch shares by region. Distribution of the share of total landings by month, averaged across fisheries within each region, for pre-catch share period (36 months before policy implementation) and post-catch share period (36 months following policy implementation). Months are rank-ordered by landings share within each region for comparability across fisheries. The regions are Alaska ($n = 2$) (**a**), New England and Mid-Atlantic ($n = 11$) (**b**), Gulf of Mexico ($n = 6$) (**c**), and Pacific ($n = 20$) (**d**), which includes fisheries off the coasts of California, Oregon, and Washington.

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Table 1 | Pooled regressions showing average season decompression over US catch share fisheries

Model	Catch share region-post interaction: Coefficient	Catch share region-post interaction: Standard error	Standard error type	Cluster variable	n
Gini coef. (OLS)	−0.0913**	0.0281	Robust	None	504
Gini coef. (OLS)	−0.0913*	0.0385	Robust	Fishery pair	504
Gini coef. (OLS)	−0.0913*	0.0368	Newey-West	None	504
Gini coef. (FL)	−0.0902***	0.0198	Delta-method	None	504
Gini coef. (FL)	−0.0902***	0.0267	Delta-method	Fishery pair	504
Months to 70% (OLS)	0.8121**	0.2525	Robust	None	504
Months to 70% (OLS)	0.8121*	0.3380	Robust	Fishery pair	504
Months to 70% (OLS)	0.8121*	0.3301	Newey-West	None	504
Months to 80% (OLS)	0.9121**	0.2905	Robust	None	504
Months to 80% (OLS)	0.9121*	0.3928	Robust	Fishery pair	504
Months to 80% (OLS)	0.9121*	0.3820	Newey-West	None	504

*$P<0.05$, **$P<0.01$, ***$P<0.001$. Difference-in-differences models include year fixed effects, fishery pair fixed effects and year × fishery pair fixed effects. FL, fractional logit.

treatment–control analyses with multiple fisheries have quantified the effects of catch shares on biological outcomes but did not examine the race to fish[1,6,22].

We analyse 39 US fisheries treated with catch shares, where a fishery is defined as a unique target species in a region (or grouping of similar species). Our sample represents all federally managed commercial fisheries in the US that have adopted market-based management and for which publicly available landings data are reported at the monthly level (monthly data are used to analyse season lengths; Supplementary Table 1, Extended Data Table 1 and Supplementary Note 1). Our sample fisheries, which contributed $402 million in total landed value in 2013, are contained within 10 of 16 distinct US catch share programs. A program may regulate one or multiple fisheries.

Matched controls for each of our 39 treated fisheries are based on a similarity hierarchy of US and Canadian fisheries that did not experience a change in treatment status (Supplementary Table 1). A first-tier match is a fishery of the same species managed in a US jurisdiction that did not implement catch share management reform at the same time. For example, we matched New England scallops that transitioned to catch share management with New England scallops that remained under command-and-control management. The second tier uses a fishery for the same species in Canada that did not implement catch share management reform at the same time. Many of the same species caught in New England, Alaska, and the Pacific Northwestern United States are also fished in Canadian waters. For example, we matched New England Atlantic cod to cod in eastern Canada. The third tier uses a US or Canadian fishery for a similar species or market that did not experience management reform. For example, we matched Gulf of Mexico red snapper, which transitioned to catch shares in 2008, to Gulf of Mexico vermilion snapper, which remained under command-and-control regulation.

The Gini coefficient, which is traditionally used to measure income inequality, provides a quantitative measure of season compression. It captures the dispersion of average monthly harvest during three-year periods before and after catch share implementation. The Gini coefficient is zero when landings are equally divided among months of the year and approaches one as landings concentrate in fewer months. Thus, the hypothesis that catch shares end (or attenuate) the race to fish translates into a statistical test of whether the policy treatment causes a decrease in the Gini coefficient relative to change in the comparison fishery within the same period. We also test this hypothesis using alternative measures of season compression: the time (in months) taken to reach 70% and 80% of the total season's landings.

The statistical model is

$$G_{itk} = \alpha_i + \beta_1 \mathrm{POST}_{it} + \beta_2 \mathrm{TREAT}_{ik} + \beta_3 \mathrm{POST}_{it} \times \mathrm{TREAT}_{ik} + \theta_t + \theta_{it} + \varepsilon_{itk}$$

where G is the Gini coefficient on landings distribution across months, or months taken to land 70% or 80% of the annual total, for year t, fishery treatment–control pair i, and treatment status k. POST and TREAT are binary variables indicating that an observation occurs after catch share implementation and that it receives treatment, respectively. Fishery pair fixed effects (α_i) control for all unobserved, fishery pair-specific, time-invariant factors. Year fixed effects (θ_t) and year–fishery pair interactions (θ_{it}) control for all time-varying factors that influence both treatment and control fisheries. The average treatment effect of catch share implementation is the difference-in-differences (DID) estimator, β_3. We estimate ordinary least squares (OLS) models, as well as fractional logit models for the Gini coefficient outcome. Fractional logit explicitly models a response variable bounded by zero and one[23,24].

Pooling data across fisheries and regions, we find an average treatment effect (ATE) on the Gini coefficient ranging from −0.0902 to −0.0913 ($P<0.01$) (Table 1), indicating that catch shares substantially reduce the concentration of landings over time. The temporal distribution of landings for a given Gini coefficient is non-unique; however, examples can illustrate the magnitude of the treatment effect (Extended Data Fig. 1). For the average time taken to reach 70% and 80% of the catch, catch shares add 0.81 and 0.91 months, respectively.

Applying difference-in-differences to individual fisheries (Supplementary Table 2) yields significant ($P<0.05$) and negative Gini treatment effects (that is, season decompression) in 20 of 39 fisheries in fractional logit models (Fig. 2 and Extended Data Fig. 2). Two commonly lauded success stories in rights-based fisheries management, Alaskan halibut and Alaskan sablefish, have sizable treatment effects of −0.14 and −0.21, respectively ($P<0.01$). The average time to land 80% of the total harvest increased by 1.1 months for halibut and by 2.3 months for sablefish, net of any changes in their control fisheries.

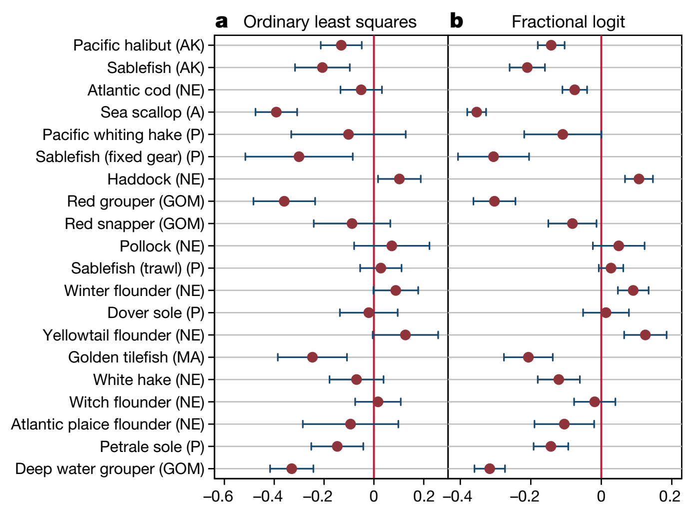

Figure 2 | Average treatment effect for individual fisheries (top 20 fisheries by value). Average change in landings Gini coefficient for OLS (**a**) and fractional logit (**b**) models. Error bars are 1.96 s.d. around point estimates. Negative point estimates that are significantly different from zero indicate season decompression. Figure includes US catch share fisheries with sufficient monthly data. Note that Atlantic sea scallop is ranked according to the portion of the fishery that is managed by catch shares (approximately 5%). The frequency of negative and significant effects for all 39 treated fisheries in our study is similar (Extended Data Fig. 2). A, Atlantic; AK, Alaska; GOM, Gulf of Mexico; MA, Mid-Atlantic; NE, New England; P, Pacific.

Table 2 | Meta-analysis showing average season decompression across US catch share fisheries

Model	Weighting scheme	Weighted average treatment effect	Weighted variance	*t* statistic	Two-sided *P* value
Gini coefficient (OLS)	Unweighted	−0.081	0.0001	−7.43	0.0000
	1/variance	−0.098	0.0001	−13.40	0.0000
	Fishery size (pounds)	−0.094	0.0014	−2.54	0.0151
	Fishery size (dollars)	−0.134	0.0002	−10.80	0.0000
	Pounds/ variance	−0.089	0.0003	−5.55	0.0000
	Dollars/ variance	−0.143	0.0002	−11.66	0.0000
Gini coefficient (FL)	Unweighted	−0.075	0.0000	−11.32	0.0000
	1/variance	−0.101	0.0000	−22.78	0.0000
	Fishery size (pounds)	−0.097	0.0006	−3.91	0.0004
	Fishery size (dollars)	−0.134	0.0001	−17.51	0.0000
	Pounds/ variance	−0.097	0.0001	−10.13	0.0000
	Dollars/ variance	−0.154	0.0001	−21.27	0.0000
Months to 70% of total yearly catch (OLS)	Unweighted	0.720	0.0104	7.06	0.0000
	1/variance	0.738	0.0043	11.21	0.0000
	Fishery size (Pounds)	0.783	0.1343	2.14	0.0390
	Fishery size (Dollars)	1.150	0.0135	9.90	0.0000
	Pounds/ variance	0.686	0.0191	4.97	0.0000
	Dollars/ variance	1.051	0.0123	9.49	0.0000
Months to 80% of total yearly catch (OLS)	Unweighted	0.812	0.0122	7.36	0.0000
	1/variance	0.696	0.0042	10.73	0.0000
	Fishery size (pounds)	0.868	0.1888	2.00	0.0527
	Fishery size (dollars)	1.318	0.0159	10.45	0.0000
	Pounds/ variance	0.835	0.0224	5.57	0.0000
	Dollars/ variance	1.429	0.0145	11.86	0.0000

$n = 39$

Individual fisheries reveal substantial heterogeneity in season decompression, reflecting differences in economic and institutional factors (Fig. 2 and Extended Data Fig. 2). The large treatment effect for Alaskan halibut (−0.14) is consistent with the extreme fishing derby that existed before catch shares, in which regulators set a TAC, opened the season, and closed the season when the fleet caught the TAC. By contrast, the smaller treatment effect in Gulf of Mexico red snapper (−0.08 change in Gini coefficient) is consistent with the pre-catch share management regime, which distributed short season openings over multiple months. By fostering a series of mini-derbies rather than one large one, Gulf red snapper management before the introduction of catch shares created less season compression for the policy to undo. In the Pacific, mixed results across fisheries are consistent with the prior use of regulation (quota allocation to a subset of vessels for some species) that did not promote highly compressed seasons. Similarly, the modest Atlantic cod treatment effect (−0.08) reflects previous regulations that may have partially prevented racing. Two New England fisheries (haddock and winter flounder, which are in the New England multispecies groundfish complex with Atlantic cod) actually have Gini treatment effects that are positive and statistically significant. This suggests possible effort substitution within the multispecies complex; as vessels spread out the catch of the high-value, high-volume Atlantic cod ($1.66 per pound, 18.5 million pounds), they necessarily compress the catch of lower value haddock ($1.36 per pound) and lower volume winter flounder (4.8 million pounds) (Supplementary Table 3).

Because US catch share fisheries vary greatly in size (between 2.0×10^2 and 1.2×10^6 pounds) and total value ($\$1.0 \times 10^3$ to $\$1.1 \times 10^8$) (Supplementary Table 3), we quantify weighted average treatment effects (WATEs) using a meta-analysis. Each fishery represents an individual 'experiment', and the WATE across fisheries is computed for each of six weighting schemes (Table 2). Results are consistently negative for Gini coefficients (positive for months to 70% and 80%) and statistically significant across models, outcomes, and weighting schemes ($P < 0.05$), although the magnitude depends on the weighting. Unweighted meta-analysis results are similar to the average treatment effect in the pooled regression. Robustness checks that exclude extremely low-volume Pacific fisheries and that analyse results separately by region are consistent with our main findings (Extended Data Table 2–8).

Our results strongly support the widely held view that catch shares attenuate the race to fish[1,2,4,5,9,11,14,17,19]. Whether fisheries are pooled to estimate an average treatment effect (Table 1) or fishery-specific treatment effects are estimated separately and combined in a meta-analysis (Table 2), catch shares are found to lengthen the season and thus ameliorate the tragedy of the commons. By slowing fishing pressure, catch shares create new incentives to reduce costs, improve product quality, time the catch to market demand, and avoid safety risks. Slowing down may also convey ecological benefits. Nevertheless, some racing is likely to remain because biological and market conditions create other incentives to concentrate harvest independent of management reform[7,25].

Despite their sizable benefits, catch shares have potential drawbacks. Concerns include industry consolidation, non-local ownership of fishing quota, decreased employment, deleterious effects on fishing communities, loss of income diversification, incentives to highgrade (discard smaller fish and continue fishing for larger, higher priced fish), management costs, and questions about the fairness of giving away a public resource to individual fishermen[2,26–30]. Although many concerns can be addressed through careful policy design[1,2,20], catch shares remain contentious in fisheries policy worldwide. For example, the US House of Representatives restricts development of new catch share programs in its bill (HR1335, 114th Congress) to reauthorize the Magnuson–Stevens Fishery Conservation and Management Act. Such restrictions are absent from the corresponding draft Senate bill (S2991, 113th Congress). As governments around the world deliberate on the benefits and costs of expanding catch share management in fisheries, our findings on ending the race to fish offer important insights.

Online Content Methods, along with any additional Extended Data display items and Source Data, are available in the online version of the paper; references unique to these sections appear only in the online paper.

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Supplementary Information is available in the online version of the paper.

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METHODS

Our identification strategy using matched control fisheries improves substantially upon previous analyses. It is difficult to quantify the impact of a management change by examining only the affected fishery (for instance, a before–after comparison of a catch share introduction) because season lengths are affected by many factors besides the management regime. Changes in the supply of substitutes, economic conditions, seasonal variation, and technological change are just a few of the factors that can influence season length and may do so concurrently with the change in management in question. Our treatment–control comparison approach is subject to a much smaller set of confounding factors than previous analyses, strengthening our claim of causality. Given the impracticality of randomized controlled trials in catch share implementation, our quasi-experimental approach to observational data provides the most reliable empirical information available on the season length effects of catch shares. Other rigorous quasi-experimental evidence of season decompression is limited to just two recent studies of selected examples[17,18].

Data. No statistical methods were used to predetermine sample size. To test our hypothesis, we first identified all federally managed fisheries in the US that have switched to catch share management and the species included under each (Supplementary Table 1, Extended Data Table 1). We compiled a panel of data from publicly available records on the National Oceanic and Atmospheric Administration (NOAA) Fisheries Statistics Division's website. This was supplemented by data sourced directly from Fisheries and Oceans Canada—which allowed us to compare season lengths with Canadian fisheries—and directly from NOAA for Atlantic sea scallops (because catch shares are applied for only part of the harvest of this species). Monthly US commercial fisheries landings data are available and complete for the years 1990–2013 and include weight in pounds or metric tons of landings by species, state, and management region. Owing to confidentiality issues concerning the monthly data, a small number of observations are unavailable in cases where the number of participating vessels was fewer than three (the 'rule of three'). Monthly data are required to observe the intra-seasonal distribution of landings.

The treated fisheries represent a wide range of species and fishery types (Supplementary Table 1). We included in our study all US catch share fisheries, with the following exceptions. Fisheries in four Alaskan programs (the American Fisheries Act Pollock Cooperative, the Bering Sea and Aleutian Islands Crab Rationalization Program, the Non-Pollock Trawl Catcher/Processor Groundfish Cooperatives (Amendment 80), and the Central Gulf of Alaska Rockfish Cooperatives Programs) transitioned to catch shares in years for which monthly landings data are not available (the NOAA stopped reporting landings data disaggregated by month after 1999 in Alaska). Two Mid-Atlantic programs (the ocean quahog Individual Tradeable Quota (ITQ) Program and the Mid-Atlantic surfclam ITQ) transitioned in the same year that monthly landings data become available for this region (1990), preventing calculation of the outcome variables (discussed below) pre-treatment. We also excluded the South Atlantic wreckfish ITQ program, for which very small numbers of participants (fewer than three in some years) triggered confidentiality rules that prevent access to complete data for the majority of the time period of analysis. For most of these programs, simple before–after comparisons of season lengths suggest that seasons extended after catch shares were introduced, and for the remaining programs either seasons did not change or no data were available[19,31] (Extended Data Table 1). Although we caution against drawing strong inferences from before–after comparisons, none of these fisheries provides evidence that contradicts our main conclusions.

Empirical strategy. In selecting control fisheries, we aimed to select fisheries that serve similar markets (and thus were affected by the same shocks in demand) and are caught using similar gear (and thus are affected by the same supply shocks), but have distinct management regimes. Descriptions of fishery management systems are provided in Supplementary Note 1. All of our controls represent fisheries that did not experience a change in treatment status at the same time the matched treated fishery received treatment. Our matches were in three categories: A) same species managed by a US management authority that did not implement catch shares at the same time; B) same species in Canada for which Canadian monthly landings are available and catch share management reform did not occur at the same time; and C) similar species or market that did not experience catch share management reform at the same time. We made decisions hierarchically, choosing an A match where available, then a B match if an A match was unavailable, and so on. Most of the matches used the same species (Supplementary Table 1). Because identification is based on a change in treatment status, our matched controls include three management types: fisheries that have never been treated with catch shares, fisheries that already had catch shares in place when the treatment on the treated fishery occurred, and fisheries that were already partially treated with catch shares when the treatment on the treated fishery occurred. Our difference-in-differences (DID) strategy is equally suited to estimating treatment effects using all three types of control[32]. What makes a fishery suitable as a control comparison is simply that its treatment status did not change at the same time as the treatment status changed in the fishery of interest. In the fishery descriptions, we refer to controls with pre-existing catch shares as 'reverse controls'.

We created a panel of total pounds landed for 39 species or species groups in 10 distinct catch share programs. In three cases, multiple species were grouped together to form a single treatment group, with the same groupings of species used on the control side. Grouping was performed in cases where species are jointly managed, serve a similar or identical market, and where relatively small total harvests make individual species-level comparisons problematic.

Using monthly landings data, we calculated an annual Gini coefficient, a measure of inequality, for each fishery and its pair. There are twelve months of landings, which we labelled $m = 1, 2, \ldots, 12$. Next, we ordered the months for a given fishery according to the landings in each month, such that the landings, L^m, formed an increasing sequence ($L^1 \leq L^2 \leq L^3 \leq \ldots \leq L^{12}$). Given the distribution of landings, ($L^1, L^2, \ldots, L^{12}$), the mean landings μ was defined as:

$$\mu = \frac{1}{12} \sum_{m=1}^{12} L^m$$

The Gini coefficient was calculated as:

$$G = 1 - \frac{1}{12^2 \mu} \sum_{q=1}^{12} \sum_{r=1}^{12} \min(L^q, L^r)$$

The Gini coefficient ranges from a minimum value of zero, when landings are equally divided among months of the year, and approaches one in cases where all landings for a given year are concentrated in a single month. Months taken to reach 70% and 80% of the annual landings were calculated by cumulatively summing each fishery's landings over the ordered series (highest amount caught to lowest) of months for each year. Linear interpolation was used for cases in which the threshold was crossed somewhere between the two monthly reports (for example, 65% after 5 months and 78% after 6 months). For most fisheries, we failed to reject simple tests for equality of variance between treated and control groups for our dependent variables (Supplementary Tables 4–6).

We performed DID regressions in order to isolate the effect of catch share management on season length. DID estimation compares the change in outcome levels over time across treatment and control groups, relying on the assumption that, absent the treatment, the difference between treatment and control outcomes would have remained constant over time. Thus, the change in this difference in the post-treatment period—the 'difference in differences'—identifies the effect of the treatment on the treated group. In this study, we defined the 'treatment' (TREAT) as the implementation of a new catch share-based fishery management program, and the 'post-implementation period' (POST) as the time of the policy change and all subsequent periods. The treatment group is the fishery or region in a given pair that underwent a policy change to catch shares, whereas the control group did not undergo such a change within the relevant time period (but could have before the sample period).

As the data permitted, we ran our model with three-year intervals before and after the policy change. Longer periods were increasingly infeasible owing to data restrictions.

We specified our regression model as $G_{itk} = \alpha_i + \beta_1 \mathrm{POST}_{it} + \beta_2 \mathrm{TREAT}_{ik} + \beta_3 \mathrm{POST}_{it} \times \mathrm{TREAT}_{ik} + \theta_t + \theta_{it} + \varepsilon_{itk}$, where G is the Gini coefficient on landings distribution across months, or months taken to land 70% or 80% of the annual total, for year t, fishery treatment–control pair i, and treatment status k. POST and TREAT are binary variables indicating that an observation occurs after catch share implementation and that it belongs to the treatment fishery, respectively. Fishery pair fixed effects (α_i) control for time-invariant factors and allow the intercept in the model to vary by individual treatment–control pair. Year fixed effects (θ_t) and year–fishery pair interactions (θ_{it}) control for time-varying factors that influence both treatment and control fisheries. The idiosyncratic error term is represented by ε_{itk}. The average treatment effect of catch share implementation is the DID estimator β_3. We first estimated the model above for all outcome variables using OLS regression. Running OLS regressions on fractional response data such as Gini coefficients can be problematic. When the dependent variable y is bounded by the unit interval [0, 1], the effect of any given explanatory variable x cannot be constant throughout the variable's range without generating predictions outside the unit interval[24]. A one-step quasi-maximum likelihood estimation approach that involves nesting a logit function within a more general form remedies the technical shortcomings of OLS and alternative models that restrict the outcome variable to the unit interval[24]. This fractional logit model has been used in several empirical studies to obtain robust estimators of conditional mean parameters in proportional response cases[23,24]. Thus, we also estimated fractional logit models in Stata using a generalized linear model (GLM) with a Bernoulli/binomial distribution and a logit link function.

We estimated standard errors for OLS models using two different approaches. The Huber–White 'robust' variance estimator calculates consistent standard errors in the presence of heteroskedasticity. The Newey–West variance estimator calculates consistent standard errors in the presence of autocorrelation in addition (with a lag up to and including three years). Standard errors in fractional logit models are maximum likelihood standard errors transformed using the delta method to obtain the standard error on the marginal effect and are robust.

We estimated individual fishery treatment effects using the model specification $G_{tk} = \alpha + \beta_1\mathrm{POST}_t + \beta_2\mathrm{TREAT}_k + \beta_3\mathrm{POST}_t \times \mathrm{TREAT}_k + \theta_t + \varepsilon_{tk}$ where G is the Gini coefficient on landings distribution across months, or months taken to land 70% or 80% of the annual total, for year t and treatment status k. POST and TREAT are binary variables indicating that an observation occurs after catch share implementation and that it belongs to the treatment fishery, respectively. The constant is α. Year fixed effects (θ_t) control for time-varying factors that influence both treatment and control fisheries. The idiosyncratic error term is represented by ε_{tk}. The average treatment effect of catch share implementation is the DID estimator β_3.

Meta-analyses. For the meta-analyses we calculated the WATE and weighted variance using different weighting schemes. To give more weight to treatment effects that are more precisely estimated, we used inverse variance weighting. To weight more economically important fisheries, we used volume (pounds landed) and dollar value (ex-vessel revenues) weightings. We also combined these weightings. Weights w for each fishery pair i for each of the resulting six weighting schemes (including unweighted), s, were applied to DID coefficients β_3 to give the WATE:

$$WATE = \frac{\sum_i \beta_{3i} w_{si}}{\sum_i w_{si}}$$

Similarly, weighted variance (WV) was calculated as:

$$\mathrm{WV} = \frac{\sum_i \mathrm{var}(\beta_{3i}) {w_{si}}^2}{(\sum_i w_{si})^2}$$

These statistics were used to calculate a t statistic:

$$t = \frac{\mathrm{WATE}}{\sqrt{\mathrm{WV}}}$$

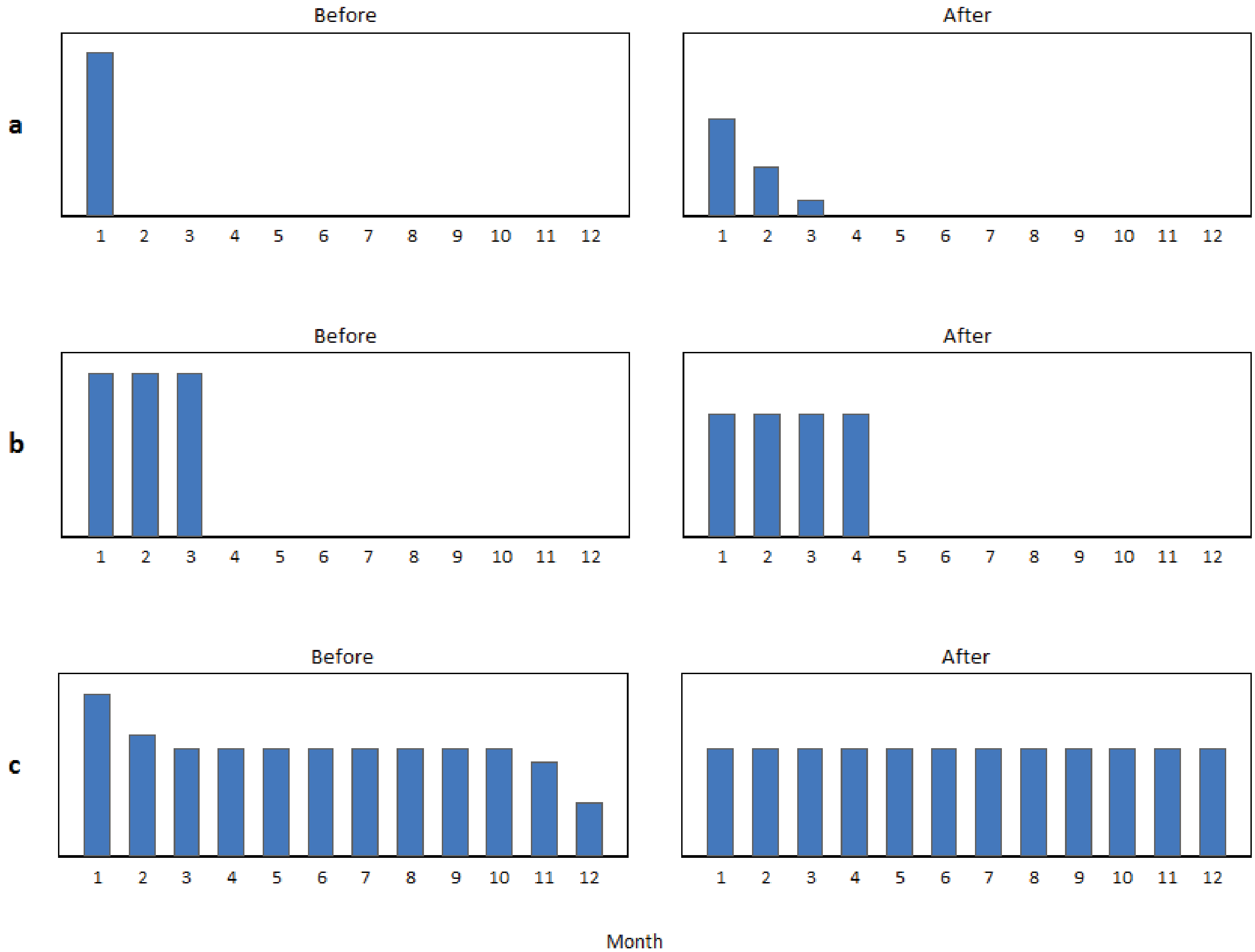
which was compared to a Student's t distribution to find a two-tailed P value associated with each WATE for both model types (OLS and fractional logit) and all outcome variables.

Sub-sample analyses. We provide ATE and WATE estimations for fishery sub-samples to demonstrate the robustness of results. In one of these robustness checks, we exclude low-quota rockfishes in the PFMC Groundfish Trawl Rationalization Program (Extended Data Table 2, 3, 8). Pacific Ocean perch, canary, widow, darkblotched, cowcod, bocaccio, and yelloweye rockfishes had relatively low quotas during the analysis period owing to overfishing concerns. We consider each of the four geographic regions separately as another robustness check: Alaskan ($n = 2$), Gulf of Mexico ($n = 6$), New England and the Mid-Atlantic ($n = 11$), and Pacific ($n = 20$) (Extended Data Tables 4–7).

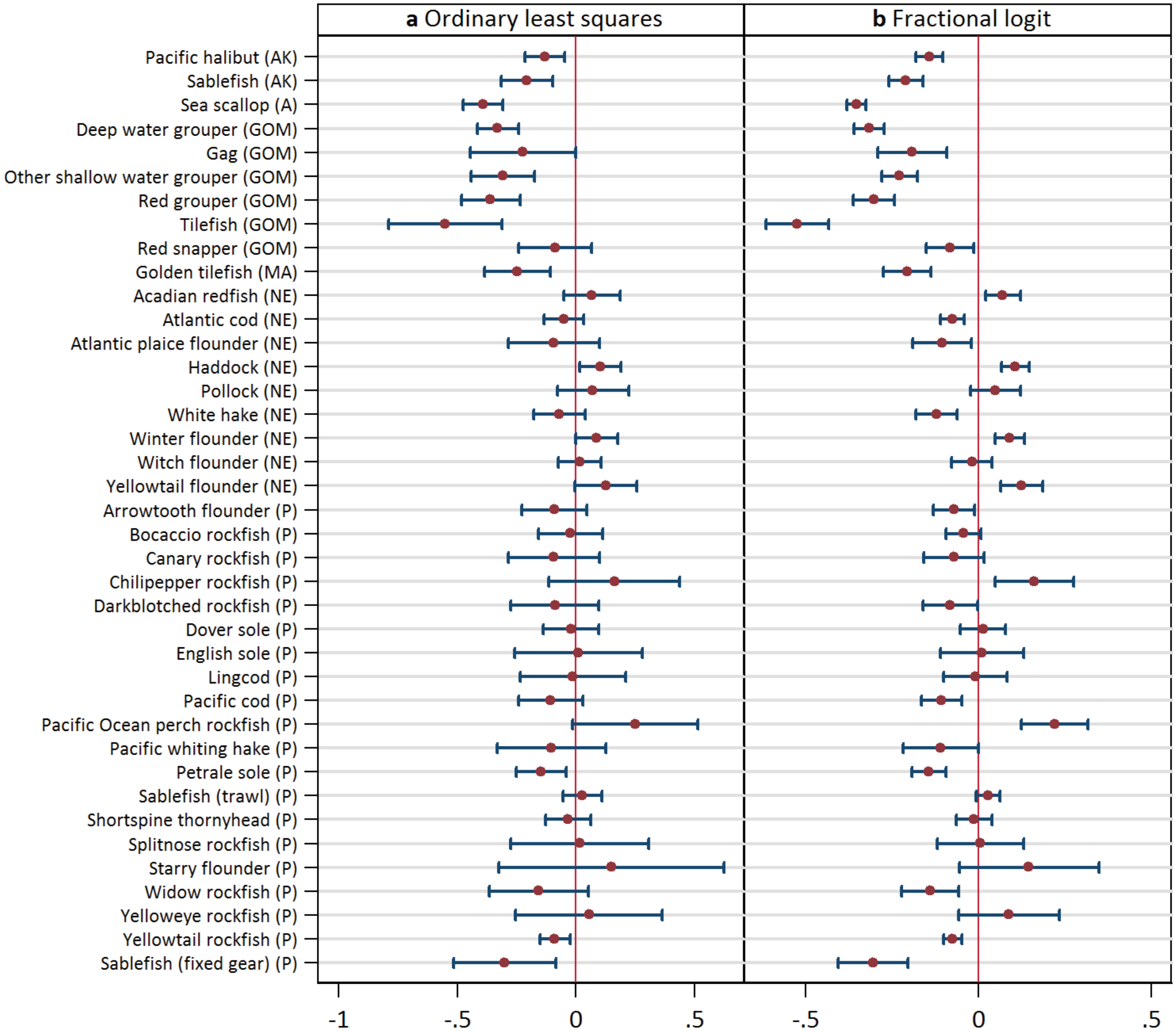
Code availability. Stata (version 11) code necessary to reproduce the findings of this study is available in the Supplementary Information (Supplementary Data and Code).

Data Availability. Data necessary to reproduce the findings of this study are available in the Supplementary Information (Supplementary Data and Code).

31. Brinson, A. A. & Thunberg, E. M. *The Economic Performance of U.S. Catch Share Programs 160* (National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 2013).
32. Shadish, W. R., Cook, T. D. & Campbell, D. T. *Experimental and Quasi-Experimental Designs for Generalized Causal Inference* (Houghton Mifflin, 2002).



Extended Data Figure 1 | Illustrative representations of season decompressions with similar magnitude to the average Gini coefficient treatment effect (around 0.08–0.09). A change in Gini coefficient of a particular size may represent one of many possible changes in the distribution. The three examples are roughly equivalent in magnitude and represent changes from landings that are extremely compressed to highly compressed (**a**), uniformly distributed over three periods to uniformly distributed over four periods (**b**), and very spread out to completely uniform (**c**).



Extended Data Figure 2 | Average treatment effect for individual fisheries (all fisheries). Average change in landings Gini coefficient for OLS (**a**) and fractional logit (**b**) models. Error bars are 1.96 s.d. around point estimates. Negative point estimates that are significantly different from zero indicate season decompression. Figure includes US catch share fisheries for which sufficient monthly data are available.

Extended Data Table 1 | Excluded catch share programs

Region	Program Name	Commencement Date	Species	Grouping	Reason for Exclusion	Before-after comparison of season length (without control) (based on cited literature)
Northeast	Mid-Atlantic Ocean Quahog ITQ Program	October, 1990	Ocean quahog *(Arctica islandica)*	Ocean quahog	A complete year of monthly data in the pre-catch share period is not available. NOAA monthly landings data is available from 1990 onward.	No change in season length [31]
	Mid-Atlantic Surfclam ITQ Program	October, 1990	Atlantic surfclam *(Spisula solidissima)*	Atlantic surfclam		No change in season length [31]
Southeast	South Atlantic Wreckfish ITQ Program	March, 1992	Wreckfish *(Polyprion americanus)*	Wreckfish	Small numbers of participants and confidentiality rules about reporting bias results.	No data available
Alaska	American Fisheries Act (AFA) Pollock Cooperatives	January, 1999	Pollock *(Gadus chalcogrammus)*	Pollock	Insufficient publicly available monthly data.	Season length increase [19]
	Bering Sea and Aleutian Islands Crab Rationalization Program	August, 2005	Red king crab *(Paralithodes camtschaticus)*	King crab	Insufficient publicly available monthly data.	Season length increase [19]
			Golden king crab *(Lithodes aequispinus)*			
			Snow crab *(Chionoecetes opilio)*	Snow crab		
	Non-Pollock Trawl Catcher/ Processor Groundfish Cooperatives (Amendment 80)	January, 2008	Atka mackerel *(Pleurogrammus monopterygius)*	Atka mackerel	Insufficient publicly available monthly data.	Season length increase [19]
			Aleutian Islands Pacific Ocean perch *(Sebastes alutus)*	Pacific Ocean perch		
			Pacific cod *(Gadus macrocephalus)*	Pacific cod		
			Flathead sole *(Hippoglossoides elassodon)*	Sole		
			Rock sole *(Lepidopsetta bilineata)*			
			Yellowfin sole *(Limanda aspera)*			
	Central Gulf of Alaska Rockfish Cooperatives Program	May, 2007	Pacific Ocean perch *(Sebastes alutus)*	Pacific Ocean perch	Insufficient publicly available monthly data.	Season length increase [19]
			Pacific cod *(Gadus macrocephalus)*	Pacific cod		
			Sablefish *(Anoplopoma fimbria)*	Sablefish		
			Shortspine thornyhead *(Sebastolobus alascanus)*	Shortspine thornyhead		
			Northern rockfish *(Sebastes polyspinis)*	Rockfishes		
			Dusky rockfish *(Sebastes ciliatus)*			
			Shortraker rockfish *(Sebastes borealis)*			
			Rougheye rockfish *(Sebastes aleutianus)*			

Prior to the implementation of catch shares in the ocean quahog and Atlantic surfclam fisheries, quarterly quotas were used to ensure year-round landing of these products. While the timing of harvest may have shifted owing to catch share implementation, the season length was already maximized[19,31]. In addition to these excluded programs, a number of individual species were excluded from analysis because there were insufficient data.

Extended Data Table 2 | Pooled regressions showing average season decompression across US catch share fisheries, excluding low-quota Pacific rockfishes

Model	Catch Share Region-Post Interaction		SE Type	Cluster Variable	N
	Coef.	SE			
Gini coef. (OLS)	-0.0966***	0.0272	Robust	None	432
Gini coef. (OLS)	-0.0966*	0.0421	Robust	Fishery Pair	432
Gini coef. (OLS)	-0.0966**	0.0361	Newey-West	None	432
Gini coef. (FL)	-0.0951***	0.0192	Delta-method	None	432
Gini coef. (FL)	-0.0951**	0.0290	Delta-method	Fishery Pair	432
Months to 70% (OLS)	0.8538***	0.2438	Robust	None	432
Months to 70% (OLS)	0.8538*	0.3703	Robust	Fishery Pair	432
Months to 70% (OLS)	0.8538**	0.3218	Newey-West	None	432
Months to 80% (OLS)	0.9581***	0.2803	Robust	None	432
Months to 80% (OLS)	0.9581*	0.4305	Robust	Fishery Pair	432
Months to 80% (OLS)	0.9581*	0.3729	Newey-West	None	432

DID models include year fixed effects, fishery pair fixed effects and year × fishery pair fixed effects. Excluded rockfishes are Pacific Ocean perch, canary, widow, darkblotched, cowcod, bocaccio, and yelloweye. $*P < 0.05$, $**P < 0.01$, $***P < 0.001$.

Extended Data Table 3 | Meta-analysis showing average season decompression across US catch share fisheries excluding low-quota Pacific rockfishes

Model	Weighting Scheme	Weighted Average Treatment Effect	Weighted Variance	t-statistic	Two-sided p-value
Gini coefficient (OLS)	Unweighted	-0.094	0.0001	-8.23	0.0000
	1/Variance	-0.102	0.0001	-13.52	0.0000
	Fishery Size (Pounds)	-0.094	0.0014	-2.54	0.0160
	Fishery Size (Dollars)	-0.135	0.0002	-10.80	0.0000
	Pounds/Variance	-0.089	0.0003	-5.54	0.0000
	Dollars/Variance	-0.143	0.0002	-11.66	0.0000
Gini coefficient (FL)	Unweighted	-0.088	0.0000	-12.61	0.0000
	1/Variance	-0.107	0.0000	-23.12	0.0000
	Fishery Size (Pounds)	-0.097	0.0006	-3.90	0.0004
	Fishery Size (Dollars)	-0.134	0.0001	-17.50	0.0000
	Pounds/Variance	-0.097	0.0001	-10.12	0.0000
	Dollars/Variance	-0.154	0.0001	-21.27	0.0000
Months to 70% of Total Yearly Catch (OLS)	Unweighted	0.831	0.0114	7.77	0.0000
	1/Variance	0.762	0.0047	11.14	0.0000
	Fishery Size (Pounds)	0.783	0.1349	2.13	0.0406
	Fishery Size (Dollars)	1.150	0.0135	9.90	0.0000
	Pounds/Variance	0.686	0.0191	4.96	0.0000
	Dollars/Variance	1.051	0.0123	9.49	0.0000
Months to 80% of Total Yearly Catch (OLS)	Unweighted	0.938	0.0136	8.05	0.0000
	1/Variance	0.915	0.0058	11.97	0.0000
	Fishery Size (Pounds)	0.868	0.1897	1.99	0.0546
	Fishery Size (Dollars)	1.318	0.0159	10.44	0.0000
	Pounds/Variance	0.835	0.0225	5.57	0.0000
	Dollars/Variance	1.429	0.0145	11.85	0.0000

Excluded rockfishes are Pacific Ocean perch, canary, widow, darkblotched, cowcod, bocaccio, and yelloweye.

Extended Data Table 4 | Meta-analysis showing average season decompression across US catch share fisheries in Alaska

Model	Weighting Scheme	Weighted Average Treatment Effect	Weighted Variance	t-statistic	Two-sided p-value
Gini coefficient (OLS)	Unweighted	-0.169	0.0007	-6.32	0.0241
	1/Variance	-0.158	0.0007	-6.17	0.0253
	Fishery Size (Pounds)	-0.164	0.0007	-6.32	0.0242
	Fishery Size (Dollars)	-0.164	0.0007	-6.32	0.0241
	Pounds/Variance	-0.154	0.0007	-5.95	0.0271
	Dollars/Variance	-0.154	0.0007	-5.97	0.0269
Gini coefficient (FL)	Unweighted	-0.176	0.0003	-10.96	0.0082
	1/Variance	-0.167	0.0002	-10.79	0.0085
	Fishery Size (Pounds)	-0.172	0.0002	-10.98	0.0082
	Fishery Size (Dollars)	-0.172	0.0002	-10.99	0.0082
	Pounds/Variance	-0.163	0.0002	-10.45	0.0090
	Dollars/Variance	-0.163	0.0002	-10.49	0.0090
Months to 70% of Total Yearly Catch (OLS)	Unweighted	1.542	0.0645	6.07	0.0261
	1/Variance	1.277	0.0501	5.70	0.0294
	Fishery Size (Pounds)	1.467	0.0575	6.12	0.0257
	Fishery Size (Dollars)	1.474	0.0580	6.12	0.0257
	Pounds/Variance	1.222	0.0507	5.43	0.0323
	Dollars/Variance	1.227	0.0506	5.45	0.0320
Months to 80% of Total Yearly Catch (OLS)	Unweighted	1.704	0.0627	6.81	0.0209
	1/Variance	1.738	0.0625	6.95	0.0201
	Fishery Size (Pounds)	1.625	0.0647	6.39	0.0237
	Fishery Size (Dollars)	1.631	0.0645	6.43	0.0234
	Pounds/Variance	1.658	0.0636	6.57	0.0224
	Dollars/Variance	1.665	0.0634	6.61	0.0221

Extended Data Table 5 | Meta-analysis showing average season decompression across US catch share fisheries in the Gulf of Mexico

Model	Weighting Scheme	Weighted Average Treatment Effect	Weighted Variance	t-statistic	Two-sided p-value
Gini coefficient (OLS)	Unweighted	-0.310	0.0007	-11.57	0.0000
	1/Variance	-0.307	0.0005	-14.38	0.0000
	Fishery Size (Pounds)	-0.266	0.0009	-8.92	0.0001
	Fishery Size (Dollars)	-0.254	0.0009	-8.54	0.0001
	Pounds/Variance	-0.288	0.0008	-10.04	0.0001
	Dollars/Variance	-0.280	0.0008	-10.15	0.0001
Gini coefficient (FL)	Unweighted	-0.274	0.0002	-18.23	0.0000
	1/Variance	-0.271	0.0002	-21.33	0.0000
	Fishery Size (Pounds)	-0.232	0.0003	-12.77	0.0000
	Fishery Size (Dollars)	-0.221	0.0003	-12.27	0.0000
	Pounds/Variance	-0.246	0.0003	-14.04	0.0000
	Dollars/Variance	-0.240	0.0003	-14.14	0.0000
Months to 70% of Total Yearly Catch (OLS)	Unweighted	2.635	0.0635	10.46	0.0000
	1/Variance	2.567	0.0378	13.21	0.0000
	Fishery Size (Pounds)	2.285	0.0754	8.32	0.0002
	Fishery Size (Dollars)	2.166	0.0759	7.86	0.0002
	Pounds/Variance	2.572	0.0693	9.77	0.0001
	Dollars/Variance	2.498	0.0640	9.88	0.0001
Months to 80% of Total Yearly Catch (OLS)	Unweighted	3.198	0.0834	11.07	0.0000
	1/Variance	3.185	0.0575	13.29	0.0000
	Fishery Size (Pounds)	2.805	0.0921	9.24	0.0001
	Fishery Size (Dollars)	2.659	0.0946	8.64	0.0001
	Pounds/Variance	3.264	0.0958	10.54	0.0000
	Dollars/Variance	3.169	0.0902	10.55	0.0000

Extended Data Table 6 | Meta-analysis showing average season decompression across US catch share fisheries in New England and the Mid-Atlantic

Model	Weighting Scheme	Weighted Average Treatment Effect	Weighted Variance	t-statistic	Two-sided p-value
Gini coefficient (OLS)	Unweighted	-0.035	0.0002	-2.47	0.0312
	1/Variance	-0.067	0.0001	-5.67	0.0001
	Fishery Size (Pounds)	0.010	0.0003	0.54	0.5975
	Fishery Size (Dollars)	-0.082	0.0002	-6.16	0.0001
	Pounds/Variance	-0.012	0.0002	-0.83	0.4263
	Dollars/Variance	-0.141	0.0002	-9.91	0.0000
Gini coefficient (FL)	Unweighted	-0.040	0.0001	-4.52	0.0009
	1/Variance	-0.091	0.0001	-12.78	0.0000
	Fishery Size (Pounds)	-0.002	0.0001	-0.20	0.8423
	Fishery Size (Dollars)	-0.083	0.0001	-10.63	0.0000
	Pounds/Variance	-0.034	0.0001	-3.76	0.0032
	Dollars/Variance	-0.162	0.0001	-19.51	0.0000
Months to 70% of Total Yearly Catch (OLS)	Unweighted	0.275	0.0173	2.09	0.0612
	1/Variance	0.381	0.0116	3.54	0.0046
	Fishery Size (Pounds)	-0.145	0.0252	-0.91	0.3820
	Fishery Size (Dollars)	0.631	0.0157	5.03	0.0004
	Pounds/Variance	-0.029	0.0180	-0.21	0.8346
	Dollars/Variance	0.929	0.0168	7.17	0.0000
Months to 80% of Total Yearly Catch (OLS)	Unweighted	0.313	0.0193	2.25	0.0458
	1/Variance	0.480	0.0128	4.25	0.0014
	Fishery Size (Pounds)	-0.176	0.0229	-1.16	0.2694
	Fishery Size (Dollars)	0.820	0.0190	5.95	0.0001
	Pounds/Variance	-0.115	0.0197	-0.82	0.4299
	Dollars/Variance	1.264	0.0188	9.23	0.0000

Extended Data Table 7 | Meta-analysis showing average season decompression across US catch share fisheries in the Pacific

Model	Weighting Scheme	Weighted Average Treatment Effect	Weighted Variance	t-statistic	Two-sided p-value
Gini coefficient (OLS)	Unweighted	-0.029	0.0003	-1.63	0.1179
	1/Variance	-0.056	0.0001	-4.98	0.0001
	Fishery Size (Pounds)	-0.096	0.0040	-1.52	0.1454
	Fishery Size (Dollars)	-0.106	0.0011	-3.25	0.0040
	Pounds/Variance	-0.072	0.0014	-1.89	0.0729
	Dollars/Variance	-0.047	0.0003	-2.62	0.0164
Gini coefficient (FL)	Unweighted	-0.025	0.0001	-2.25	0.0362
	1/Variance	-0.047	0.0000	-6.68	0.0000
	Fishery Size (Pounds)	-0.097	0.0018	-2.27	0.0344
	Fishery Size (Dollars)	-0.103	0.0005	-4.79	0.0001
	Pounds/Variance	-0.068	0.0006	-2.68	0.0143
	Dollars/Variance	-0.039	0.0001	-3.36	0.0031
Months to 70% of Total Yearly Catch (OLS)	Unweighted	0.308	0.0279	1.84	0.0799
	1/Variance	0.448	0.0102	4.44	0.0003
	Fishery Size (Pounds)	0.781	0.3941	1.24	0.2277
	Fishery Size (Dollars)	0.909	0.0948	2.95	0.0079
	Pounds/Variance	0.520	0.1055	1.60	0.1253
	Dollars/Variance	0.255	0.0225	1.70	0.1053
Months to 80% of Total Yearly Catch (OLS)	Unweighted	0.282	0.0323	1.57	0.1331
	1/Variance	0.354	0.0080	3.97	0.0008
	Fishery Size (Pounds)	0.858	0.5574	1.15	0.2641
	Fishery Size (Dollars)	0.859	0.1257	2.42	0.0250
	Pounds/Variance	0.649	0.1488	1.68	0.1083
	Dollars/Variance	0.427	0.0313	2.42	0.0254

Extended Data Table 8 | Meta-analysis showing average season decompression across US catch share fisheries in the Pacific (excluding low quota rockfishes)

Model	Weighting Scheme	Weighted Average Treatment Effect	Weighted Variance	t-statistic	Two-sided p-value
Gini coefficient (OLS)	Unweighted	-0.038	0.0005	-1.77	0.0984
	1/Variance	-0.059	0.0001	-4.87	0.0002
	Fishery Size (Pounds)	-0.096	0.0040	-1.51	0.1532
	Fishery Size (Dollars)	-0.106	0.0011	-3.24	0.0060
	Pounds/Variance	-0.071	0.0014	-1.89	0.0803
	Dollars/Variance	-0.047	0.0003	-2.61	0.0207
Gini coefficient (FL)	Unweighted	-0.033	0.0002	-2.51	0.0248
	1/Variance	-0.050	0.0001	-6.45	0.0000
	Fishery Size (Pounds)	-0.097	0.0018	-2.26	0.0400
	Fishery Size (Dollars)	-0.103	0.0005	-4.76	0.0003
	Pounds/Variance	-0.068	0.0006	-2.67	0.0183
	Dollars/Variance	-0.038	0.0001	-3.33	0.0049
Months to 70% of Total Yearly Catch (OLS)	Unweighted	0.394	0.0399	1.97	0.0689
	1/Variance	0.450	0.0124	4.04	0.0012
	Fishery Size (Pounds)	0.782	0.3972	1.24	0.2354
	Fishery Size (Dollars)	0.910	0.0961	2.94	0.0108
	Pounds/Variance	0.519	0.1061	1.59	0.1335
	Dollars/Variance	0.254	0.0226	1.68	0.1142
Months to 80% of Total Yearly Catch (OLS)	Unweighted	0.351	0.0468	1.62	0.1272
	1/Variance	0.601	0.0169	4.63	0.0004
	Fishery Size (Pounds)	0.858	0.5617	1.14	0.2717
	Fishery Size (Dollars)	0.859	0.1274	2.41	0.0305
	Pounds/Variance	0.648	0.1501	1.67	0.1165
	Dollars/Variance	0.427	0.0315	2.40	0.0308