The I, the T or the Q? Which fishing opportunity attributes are associated with sustainable fishing?

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Abstract

While several prominent studies link the use of individual transferable quotas (ITQs) to sustainable fishing, it remains unclear which attributes of this system (i.e., individual, transferable, or quota), or any other system, lead to sustainable outcomes. To test for a linkage between management systems and sustainable fishing, we systematically classified how fishing opportunities are allocated for 443 fish stocks from 1990 to 2018 to produce the largest database of its kind. Using mixed-effects models and a difference-in-differences approach, we tested the occurrence of system attributes against two metrics of sustainable fishing: mortality (i.e., overfishing) and biomass (i.e., overfished). Our results reveal that quota limits and individual allocation reduce the probability of overfishing, but offer no evidence supporting the transferability of fishing opportunities or the length of time they are held for. These results highlight the importance of considering specific attributes in the design of fisheries management systems.

1. Introduction

Individual transferable quotas (ITQs), where harvest limits are held individually, for a long duration, and can be freely transferred, are an increasingly used fisheries management system throughout global fisheries[1,2]. While several prominent studies have linked the use of ITQs to sustainable fishing[3,4], the effect of each ITQ attribute (i.e. the I, the T, and the Q), remains underexplored and the lessons for policy design unclear[5].

For each ITQ attribute, theoretical claims have been made supporting a link to sustainable fishing, but counterclaims have also been raised. Limiting catches through quota has the advantage over limiting fishing effort (e.g. time at sea, number of hooks or pots) that it is more closely tied to fishing mortality[6,7] and more predicable to control[8,9], although quota limits may be more difficult to enforce and over-quota catches simply discarded at sea[10,11]. Allocating fishing opportunities to individuals empowers fishers to choose when to use them[12], including during lower impact fishing seasons, however the common-pool aspect of fish stocks and thus the incentive for individuals to fish more remains[10]. Transferability in fishing opportunities will lead to concentration in the hands of the most profitable businesses[6,13] who may be more likely to pay for management[14] of a smaller fleet[15], but profitability is not synonymous with efficiency given unaccounted for externalities[7,16], and transferability of fishing opportunities and fleet contraction can still occur through vessel sale if quota trade is prohibited.

Beyond these ITQ attributes, there is little literature on the attributes used in alternative allocation systems, such as pooling (i.e. opportunities are fished collectively without allocation to individuals), leasing, rationing throughout the year, and leaving the industry to self-govern (e.g. the allocation of fishing opportunities to a cooperative, not including initial individual allocation that is later grouped by cooperatives[17]). While we explore these other attributes and their link to fisheries sustainability in this article, we mainly focus on the I, T, Q attributes as this is the domain where theories have been advanced.

The allocation of fishing opportunities is closely linked to duration, and several studies have claimed that when the duration of exclusive fishing opportunities is sufficiently long and secure, the long-term sustainability of the fish populations is in the interest of fishers themselves as they will bear the consequences of (un)sustainable behaviour[18,19]. This is disputed, however, as other studies have noted that the common-pool aspect of fish stocks and the incentive to overfish remains, hence the need for enforcement[5], and long-term property rights in other sectors have still led to unsustainable behaviour[5].

As many of the theoretical claims linking ITQ attributes to sustainable fishing are contested, it is especially important to test the empirical effect of existing fisheries management systems. Unfortunately, much of the existing empirical literature does not distinguish between the different attributes of management systems (Table 1) and some studies have used contested proxies as metrics of sustainable fishing[20]. By ignoring attributes, the control groups used in these studies also suffer as all other management systems, including systems with no management at all, are grouped together. The few empirical studies that analyse system attributes show no conclusive evidence that individual allocation, transferability, or duration are associated with sustainable fishing beyond the benefits of quota management (Table 1).

[Table 1]

As there are conflicting theoretical claims and as the empirical evidence on specific attributes is limited and ambiguous, an important research question remains: Which attributes of fisheries management systems, if any, are associated with sustainable fishing? For this purpose, we compiled the largest dataset on fisheries management systems to date, covering 1990–2018, and tested different systems and their attributes against two metrics of sustainable fishing:

mortality (i.e., whether a fish stock is subjected to overfishing) and biomass (i.e., whether a fish stock is overfished).

2. Results

Fisheries management systems

The most frequently observed fisheries management system in our dataset was total effort (TE, number of stocks = 174, Figure 1A), where an input to fishing is managed at the fleet level. The second most observed management system was individual transferable quota (ITQ, n=151) followed closely by total quota pool (TQP, n=112), where a quota cap is set and fished collectively by the fleet until it is exhausted. Individually rationed quota pool (IRQP, a collective quota system where quota is allocated in rationed periods over the year, e.g. a weekly limit for vessels) and individual quota (IQ) were also frequently observed (n=63 and n= 46, respectively, Figure 1A). Other allocation systems were extremely rare: rationed individual quota (RIQ, n= 4, where individual quota is allocated for a shorter term than a full season), self-governed quota pool (SGQP, n=4, where quota is formally allocated to a group such as a cooperative), individual transferable effort (ITE, n=3) and rationed quota pool (RQP=, n=2, where quota is allocated to the fleet, for a shorter time than one fishing season).

[Figure 1]

Regarding the duration for which individual quota (IQ, ILQ, ITQ) are held, most individual quota was held with a ‘legal ability’ to change allocations (e.g. by changes in the fisheries management plan, n=77, Figure 1B). Other durations were all also frequently observed (indefinite, n= 40, multiple seasons, n=35 and for one single season, n=31, Figure 1B).

Sustainable fishing indicators

We found that *overfishing* frequently occurred in all management systems and regions. The regions with the highest shares of overfishing were the Mediterranean & Black Sea region and northern Europe with 84 percent and 69 percent of observations, respectively. TE, unregulated, RQP, RIQ, and ITE management regimes had the largest shares of overfishing occurring, ranging between 71 and 100 percent of observations. In contrast, TQP, IRQP, ITQ, and individual leasable quota (ILQ) management regimes had the lowest share of overfishing ranging between 30 and 36 percent of observations (Figure 2A).

Of the total sample, a smaller amount of fish stocks, only 32 percent, were in an *overfished* state. Individual effort (IE) was the management regime with the largest share of fish stocks in an *overfished* state with 71 percent of observations, followed by TE and unregulated with 45 and 44 percent respectively (Figure 2B).

Effects of fisheries management systems on sustainable fishing indicators

Several fisheries management systems reduced the probability of *overfishing* and/or being in an *overfished* state when compared to the control system of TE (Figure 2C). Strong effects for reducing *overfishing* were found for individual quota systems (including ITQ, ILQ, and IQ), although the strongest effect was found for SGQP (Figure 2C). TQP, another form of pooled quota, also significantly reduced the probability of *overfishing*, although the effect was smaller (Figure 2C). ILQ and ITE reduced the probability of *overfished* biomass (Figure 2C), although there were few of these systems and the confidence intervals are wide.

[Figure 2]

Disentangling the effects of the I, the T, and the Q on sustainable fishing

Without controlling for other factors (i.e., region, time, fish stock), systems with the attributes of quota limits, individual allocation, and transferability had lower frequencies of *overfishing* and *overfished* states*,* with the largest difference for quota limits (71 percent without versus 40 percent with quota limits, Figures 3A and 3B).

Association between attributes and sustainable fishing (mixed regression models): Controlling for other factors in the mixed-model analysis, we found a reduced probability for *overfishing* when fisheries were under quota limits and/or when fishing opportunities were allocated individually (Figure 3C), with the largest effect found for quota limits. We found that the predicted probabilities of overfishing were, on average, 0.5 *without* quota versus 0.3 *with* quota. For individual allocation, the probability of overfishing *without* individual allocations was, on average, 0.45 versus an average probability of 0.25 for a stock *with* individual allocations (Figure B1). However, considerable uncertainty in the random effects resulted in wide prediction confidence intervals (Figure B1). For transferability, despite a lower occurrence of overfishing (Figure 3A), no significant effect was found when other factors were accounted for in the mixed-model analysis (Figure 3C). None of the attributes had a significant effect for stocks being in an *overfished* state (Figure 3C). We found no significant difference in the probability of *overfishing* when systems with longer durations were compared to those allocated for a single season*,* although there was an increased probability of an *overfished* state when fishing opportunities were allocated for fixed multiple seasons (Figure 3D).

Difference-in-differences: We found a significant reduction in the probability of overfishing for the addition of Q (fisheries transitioning from IE to IQ) and for the addition of I (TE to IE) (Figure 4). Where multiple attributes were jointly added to a system, we found a reduced probability of *overfishing* and the *overfished* state where pooled quota fisheries transitioned became individual and transferable (i.e. transitioned to ITQ) but found no significant effect for

TE managed fisheries that became quota, individual, and transferable (i.e. transitioned to ITQ). This finding may be regionally confounded as 18 of the 20 treatment fisheries that transitioned from TE to ITQ were Australian fisheries in the early 1990s. None of the transitions were associated with a change in the probability of stocks being *overfished* (Figure 4).

Refining the DiD approach to 22 paired treatment and control fisheries, where treatment fisheries transitioned from pooled quota to individually allocated quota revealed no significant change in the probability of *overfishing* or *overfished* outcomes (Figure 4).

Sensitivity test using mortality and biomass trends

The analysis of the trend indicators showed that IE increased the probability of a declining trend in *overfishing* (Table B2), while these systems were not associated with reduced *overfishing* using the sustainability threshold (Figure 2). We found the reverse for ITQ and TQP (i.e. while these systems reduced the probability for *overfishing,* they reduced the probability of an increasing trend for stocks that were experiencing *overfishing*). We found no significant change in the probability of an increasing trend in biomass for *overfished* stocks under any management system (Table B2). We also found no significant change in trends for Q, I, T, or D (Figure B2 and B3). Using the DiD approach, we found a small effect on the increase in the probability of reduced *overfishing* when fisheries transitioned from TE to IE (the addition of I) (Figure B4).

Sensitivity test using alternative thresholds for overfishing and overfished

Applying alternative sustainability thresholds (*high overfishing*: $F/F_{msy} > 1.5$; *highly overfished*: $B/B_{msy} < 0.5$) resulted in changes to the significant effects (Table B3). Whereas IRQP, IE, and unregulated fisheries did not have an effect at the original *overfishing* threshold (Figure 2C), these systems were associated with a reduced probability of *high overfishing* (Table B3). IE systems also has a significant effect on biomass at a *highly overfished* level (Table B3).

At the attribute level, the results were largely unchanged when alternative sustainability thresholds were applied (i.e., a reduced probability of *high overfishing* with individual allocation and quota limits) and the effect sizes increased (Figure B5). The lack of effect for duration also remained unchanged (Figure B6).

The results from the DiD analysis shifted considerably with alternative sustainability thresholds, with several more transitions reducing the probability of *high overfishing* (Figure B7). Adding Q (IE to individual quota; TE to non-individual quota) and adding I (TE to IE; non-individual quota systems to individual quota) resulted in a reduced probability of *high overfishing* (Figure B7). Transitioning from non-individual quota to ITQ reduced the probability of a *highly overfished* state (Figure B7). In contrast, transitioning from TE to IE increased the probability of a *highly overfished* state occurring (Figure B7).

3. Discussion

We set out to understand the degree to which fishery management systems, and in particular systems that include I, T, Q, and/or D, affect sustainable fishing. After classifying management systems used in hundreds of fisheries around the world, we found that management systems using quota limits, particularly those allocated individually (IQ, ILQ, ITQ), reduced the probability of *overfishing* compared to TE management. ILQ and ITE were the only systems associated with a reduction in the probability of stocks being *overfished*, with considerable uncertainty.

Disentangling the effects of I, T, and Q as system attributes, we found that Q and I were associated with large reductions in the probability of *overfishing*, and that this effect was stronger when we applied an alternative threshold for overfishing (i.e., *high overfishing*, F/F_{msy} >1.5). These results were only somewhat reflected in biomass indicators; individual allocation increased stock biomass for overfished stocks, but not to a level that prevented the probability of stocks remaining in an overfished state. From these results, we conclude that quota systems tend to outperform effort systems in terms of delivering sustainable fishing, and that individual systems tend to outperform systems with total, pooled limits. The result for individual allocation, however, seems to be largely driven by individual quota systems (I+Q, Figure 2) and is thus not entirely independent (i.e. I acts in interaction with Q).

Quota limits may contribute to fisheries sustainability through their direct link to fisheries mortality (i.e., closing a fishery when the quota has been fished), while effort restrictions have a margin of uncertainty in their appropriate levels within the year[21]. Moreover, when effort restrictions are used, fishers can invest in greater efficiencies in catch and mortality per unit of restricted effort (i.e., technological creep or input substitution), which severely complicates the setting of effort limits at sustainable levels[8,9].

The reduced probability of *overfishing* in individual systems could potentially be caused by the elimination of the race to fish in individual systems[12], which may result in a more targeted fishery and a reduced need to discard fish[14,22,23]. It may also result in catches that are lower compared to total allowable catches[4]. A longer fishing season may aid enforcement (e.g. in a fishery with a very short season it may be more difficult for coastguards to monitor over-quota catches or illegal discarding)[22], as would the accountability of individual allocations as these are held (and exceeded) by a fisher or a company rather than the entire fleet.

We found no effect for either the transferability of fishing opportunities or their duration, which suggests that the casual mechanisms underlying our findings for individual allocation may not be related to secure property rights in fisheries, or the use of market-based systems, as has been suggested in previous literature[3,12].

Costello et al. (2008) [3] found that 'catch shares' (specifically ITQs) prevented fisheries collapse, defined as landings below 10 percent of historical levels. While the study was the first of its kind, it suffered from several shortcomings. In the study, control fisheries were not classified and the comparison group, all non-ITQ fisheries, included many unregulated fisheries, making it impossible to disentangle the effect of implementing whether a reduced probability of collapse was due to I, T, or Q attributes[5]. In addition, it has been demonstrated that landings data, the proxy used for sustainable fishing, is a poor indicator of stock status[20]. Subsequent studies have nuanced these results. For instance, a subsequent study by the same authors[24] addressed some of the issues by investigating the impact of ITQs on fisheries that already had quota limits in place, and found that effects were still present, although weaker, than in the earlier study (Table 1). Other, more nuanced studies found mixed results for the sustainability benefits of management systems (Table 1). The few studies that have analysed specific system attributes have consistently found that Q improves sustainable fishing, a weak effect for I, and no consistent effect for either T or D (Table 1). Our findings are similar, as we found a reduced probability of *overfishing* for fisheries managed by Q and I but not for T or D.

While our study addresses many of the confounding issues in previous literature, several limitations remain. First, we cannot guarantee that our control and treatment fisheries are similar, for example regional circumstances may differ even for adjacent regions [25], or that fisheries undergoing management change may undergo transitions due to a current or recent fisheries collapse [15,26]. Second, the scope of this study is limited to governmental policy, and thus in our classification method we relied on the legal definitions of fisheries management systems. Systems may differ from what is described on paper or may develop important attributes in parallel to the governmental system (e.g. producer organisations and fishing co-operatives may pool fishing opportunities that were initially individually allocated). Similarly, the legal definitions of duration may differ from the perceived duration of fishing opportunities based on historical precedent. However, our result for duration based on legal definitions aligns with [27] who used perceived duration. Differentiating between systems as defined by policy and systems as they operate in practice is one area for future research and even further nuance in studying fishing opportunities. Third, our approach relies on defined thresholds for overfishing and overfished states and does not allow for comparison with previous work that studied continuous indicators of fish stocks[28,29]. We believe, however, that higher or lower fishing pressure can only be assessed against a defined threshold (i.e., an increase in fishing pressure from a low base could still be sustainable).

Based on our methodology and new dataset of fisheries management systems, we found evidence that both Q and I attributes were associated with a reduced probability of *overfishing*. The effect of different management attributes on sustainable fishing was not ubiquitous, however, as this finding was only slightly reflected in the probability of a stock being *overfished* and we found no benefit for stocks already under quota transitioning to individual quota or individual transferable quota when we matched these to control fisheries that continued to use pooled quota. Whereas some previous studies have emphasised that market-based systems (i.e., the presence of transferability) or those with strong property rights (i.e., a long duration) are associated with sustainable fishing, these benefits disappear with proper controls for other attributes of fisheries management systems. These results highlight the importance of considering specific attributes in the design of fisheries management systems.

4. Methods

Data collection

Management data: To classify fisheries management systems, we used a combined primary and secondary research approach by reviewing government legislation and existing fisheries literature as well as consulting fisheries managers and research specialists. In total, we consulted 230 experts for classification queries; 173 replied; of which 116 either provided or confirmed classifications. The resulting dataset is stored online with open access for further verification and use (fishing-opportunities-database: https://docs.google.com/spreadsheets/d/1UaKeXxEfVYCp5xzZwOHAnIRf1UzE484G9k1YL4SaynM/edit).

Biological data: For data on our sustainability metrics we used the RAM legacy database v4.491 (https://www.ramlegacy.org/, RAM Legacy Stock Assessment Database (2018)). These data were extracted from stock assessment documents with information on estimated annual biomass (spawning stock biomass or total stock, we refer to both of these measures as B) and exploitation rates (instantaneous fixing mortality or exploitation ratios (catch/total biomass), we refer to both of these measures as F). We only used assessments which also estimated target reference points that would generate maximum sustainable yield (i.e. F_{msy} and/or B_{msy}). Stocks were only included if they had five years of data on F/F_{msy} and/or B/B_{msy} from 1990 to 2018.

Management systems classifications

We developed 12 exhaustive classifications of management regimes based on a decision tree of potential attributes (Figure 1). Classifying management systems based on attributes in a decision tree allowed for the standardisation of systems where existing definitions were vague and allowed us to control for system attributes in a straightforward manner. Each branch in the decision tree (Figure 1) indicated the presence or absence of a system attribute (e.g. the first branch indicated whether quota or effort management was used). The blue-shaded boxes in Figure 1 are the 12 exhaustive classifications used in this study.

Where multiple allocation systems were used by a fisheries administration to manage a fish stock (e.g. different systems for coastal and industrial fleets), we assigned a percentage to each system based on the size of the allocation to each subsystem. Similarly, where multiple fisheries administrations exploited the same fish stock, we assigned a percentage to each fisheries administration based on the size of the allocation to each fishing administration, or, if no formal shares existed, the size of catches. The resulting stock classifications were thus a combination of systems used between administrations (where applicable) and within administrations (where applicable). If the use of multiple management systems prevented any one system from representing 75 percent of the fishing pressure for a fish stock, then we did not assign a classification to that fish stock as it was a 'mixed system' (following [4]). Particular system attributes (e.g. quota, individual) could reach the 75 percent threshold if they were present in multiple systems leading to the inclusion of these stocks in the attribute-level analysis.

In addition to the method for allocating fishing opportunities, we also classified the duration of fishing opportunities into four categories: single season, fixed multiple seasons, indefinite, or of an unspecified duration with the legal ability to change allocations (Figure 1B, further details in Appendix A). Individual allocation and duration are often used as interchangeable terms (e.g. analysis of 'catch shares'); however, duration operates as an independent attribute that can vary across all allocation types, as confirmed by the resulting classifications (**fishing-opportunities-database**). We only assessed duration for individual systems, where fishing opportunities were allocated as a separate unit from the fishing licence which may have had its own specified duration.

Sustainability definitions

To define sustainable fishing, we assessed fish stocks against two metrics (in line with [4,29]): fishing mortality divided by the fishing mortality needed to achieve maximum sustainable yield (F/F_{msy}), and biomass divided by the biomass that can produce maximum sustainable yield (B/B_{msy}). We defined a fish stock as subjected to *overfishing* when the fishing mortality was higher than 1.1 times F_{msy} (following [4]) and a fish stock as *overfished* when the stock biomass was lower than 0.8 B/B_{msy} (following[30]). We only included stocks from the year that F/F_{msy} was at least 0.5 (where data on F/F_{msy} was available) to control for fisheries that were not yet developed or of little commercial interest.

Sensitivity analyses: Due to a potential delay between management change and sustainable fishing [15], we included trend indicators for mortality and biomass to assess whether stocks that did not meet sustainable fishing metrics were trending toward the threshold. When a stock was experiencing *overfishing* (i.e., $F/F_{msy} >1.1$), but the level of F/F_{msy} was lower compared to the average of the previous three years, the observation was recorded as *decreasing mortality*. When a stock was *overfished* (i.e., $B/B_{msy} < 0.8$), but the level of B/B_{msy} was higher compared to the average of the previous three years, the observation was recorded as *increasing biomass*.

As a second sensitivity analysis, we used two alternative thresholds for the definition of overfishing and overfished (both also used in [4]), for *high overfishing* ($F/F_{msy} > 1.5$) and *highly overfished* ($B/B_{msy} < 0.5$).

Data analyses

To estimate the effect of management systems and their attributes on fisheries sustainability we used two modelling approaches: (1) a set of mixed-effects regressions testing both systems and attributes, and how these were associated to fisheries status; and (2) a difference-in-differences (DiD) approach that tested systems where attributes changed (also using mixed effects).

The mixed-effects modelling framework allowed for the introduction of random effects for variables where the sustainability indicators were more likely to share a similar response. For example, a response of a stock in one region to a management system was more likely to correlate to the response of another stock in the same region[31].

First, we modelled the sustainable fishing metrics *S* for region *r*, stock s, and year *t* as a function of the fisheries management system (and its multiple attributes):

$$S_{r,s,t} = \beta_1 M_{r,s,t} + R_r + R_s + \varepsilon_{r,s,t} \qquad (1)$$

where $M_{r,s,t}$ is a dummy variable for the management system in place, R_r is a random effect dummy variable for the region, R_s is a dummy variable for the stock-specific random effect, and $\varepsilon_{r,s,t}$ is the error term. We compared the effects of all management systems against *total effort* (TE) as a control group as there are very few *unregulated* fisheries in our dataset.

Second, we modelled the sustainable fishing metrics as a function of the attributes I, T, and/or Q reflecting the theoretical literature (Table 1):

$$S_{r,s,t} = \beta_1 Q_{r,s,t} + \beta_2 I_{r,s,t} + \beta_3 T_{r,s,t} + R_r + R_s + \varepsilon_{r,s,t} \qquad (2)$$

The metrics of sustainable fishing was modelled by dummy variables Q (quota), I (individual) and T (transferable). Random effects were the same as in Equation (1).

We modelled the impact of the duration of fishing opportunities as follows:

$$S_{r,s,t} = \beta_1 D_{r,s,t} + R_r + R_s + \varepsilon_{r,s,t} \qquad (3)$$

where $D_{r,s,t}$ represents the duration of fishing opportunities in a management system. We compared the effects of duration against *single season* as a control group. Random effects were the same as for Equations (1) and (2).

As a second approach, we employed a DiD analysis for all transitions where a Q, I, or T element was "added", for instance a transition from non-individual effort management to individual effort management (addition of I), or a transition from individual quota to ITQ (addition of T). We also employed DiD for transitions where multiple elements were added, i.e., a transition from non-individual effort to ITQs (addition of Q, I, and T). This second approach is commonly used for analysing time series data where systems that undergo a change (i.e., treatment) are compared to systems that remain the same (i.e., control). A key assumption in this approach is that treatment stocks would have followed a similar trajectory to control fisheries if no change had occurred[32]. DiD modelling was previously employed to study the effects of IQs, ILQs, and ITQs on sustainable fishing (Table 2).

Equation 4 represents the DiD approach where treatment stocks were compared to control stocks:

$$S_{r,s,t} = \beta_1 Tr_{r,s,t} + R_r + R_s + \varepsilon_{r,s,t} \quad (4)$$

The sustainable fishing metrics were modelled by dummy variable Tr (treatment, i.e., addition on I, T, or Q in the treatment fishery, a dummy variable which was coded 1 after the addition of the attribute and coded 0 for control stocks or prior to introduction of the attribute in treatment fisheries). The other variables are the same as Equations (1)–(3).

For a subset of stocks (n=22), we matched treatment and control stocks for the same species in the same region or regions closely located to one another (Table A2). This approach controlled for confounding circumstances, such as changes in demand or climate change impacts that affected particular species and regions[32]. Treatment fisheries transitioned from pooled quota to individual allocation while control fisheries remained under pooled quota. Previous research requested such an approach be undertaken to separate the effects of attributes of I(T)Q systems from the effects of quota management (Branch, 2009; Bromley, 2009). For this analysis, we grouped all individually allocated quota systems due to the small sample size. For this approach we included a random effect for each treatment and control pair:

$$S_{r,s,t} = \beta_1 Tr_{r,s,t} + \beta_2 P_{r,s,t} + \beta_3 Tr_{r,s,t} * P_{r,s,t} + R_c + R_s + \varepsilon_{r,c,s,t} \tag{5}$$

The sustainable fishing metrics S were modelled by dummy variable Tr (treatment), P (before and after treatment) and their interaction, β_3 represents the DiD estimator[32]. R_c is a dummy variable for the treatment and control pair; the rest of the random effects were the same as in the other equations.

For each model, we assumed that the residuals followed a first order autocorrelated process which controlled for the fact that the time-series observations were serially correlated at the stock-level. All models were implemented using the package GlmmTMB [33] in R studio version 1.1.463[34].

References

1. (EDF) Environmental Defense Fund. Sustainable Fisheries Map: http://fisherysolutionscenter.edf.org/map. (2018).

2. Chu, C. Thirty years later: The global growth of ITQs and their influence on stock status in marine fisheries. *Fish Fish.* **10**, 217–230 (2009).

3. Costello, C., Gaines, S. D. & Lynham, J. Can catch shares prevent fisheries collapse? *Science (80-.).* **321**, 1678–1681 (2008).

4. Melnychuk, M. C. *et al.* Can catch share fisheries better track management targets? *Fish Fish.* **13**, 267–290 (2012).

5. Bromley, D. W. Abdicating Responsibility: The Deceits of Fisheries Policy. *Fisheries* **34**, 280–290 (2009).

6. Innes, J., Pascoe, S., Wilcox, C., Jennings, S. & Paredes, S. Mitigating undesirable impacts in the marine environment: A review of market-based management measures. *Front. Mar. Sci.* **2**, 1–12 (2015).

7. Squires, D. *et al.* Effort rights-based management. *Fish Fish.* **18**, 440–465 (2017).

8. Marchal, P. *et al.* Impact of technological creep on fishing effort and fishing mortality, for a selection of European fleets. *ICES J. Mar. Sci.* **64**, 192–209 (2007).

9. Palomares, M. L. D. & Pauly, D. On the creeping increase of vessels' fishing power. *Ecol. Soc.* **24**, 4–11 (2019).

10. Sumaila, U. R. A cautionary note on individual transferable quotas. *Ecol. Soc.* **15**, (2010).

11. Acheson, J., Apollonio, S. & Wilson, J. Individual transferable quotas and conservation: A critical assessment. *Ecol. Soc.* **20**, (2015).

12. Birkenbach, A. M., Kaczan, D. J. & Smith, M. D. Catch shares slow the race to fish. *Nature* **544**, 223–226 (2017).

13. Arnason, R. Property rights in fisheries: How much can individual transferable quotas accomplish? *Rev. Environ. Econ. Policy* **6**, 217–236 (2012).

14. Branch, T. A. How do individual transferable quotas affect marine ecosystems? *Fish Fish.* **10**, 39–57 (2009).

15. Isaksen, E. T. & Richter, A. Tragedy, property rights, and the commons: Investigating the causal relationship from institutions to ecosystem collapse. *J. Assoc. Environ. Resour. Econ.* **6**, 741–781 (2019).

16. Ryan, R. W., Holland, D. S. & Herrera, G. E. Ecosystem externalities in fisheries. *Mar. Resour. Econ.* **29**, 39–53 (2014).

17. Rahimi, S., Gaines, S. D., Gelcich, S., Deacon, R. & Ovando, D. Factors driving the implementation of fishery reforms. *Mar. Policy* **71**, 222–228 (2016).

18. Grafton, R. Q. *et al.* Incentive-based approaches to sustainable fisheries. *Can. J. Fish. Aquat. Sci.* **63**, 699–710 (2006).

19. Arnason, R. Fisheries self-management under ITQs. *Mar. Resour. Econ.* **22**, 373–390 (2007).

20. Branch, T. A., Jensen, O. P., Ricard, D., Ye, Y. & Hilborn, R. Contrasting Global Trends in Marine Fishery Status Obtained from Catches and from Stock Assessments.

Conserv. Biol. **25**, 777–786 (2011).

21. Stefansson, G. & Rosenberg, A. A. Combining control measures for more effective management of fisheries under uncertainty: Quotas, effort limitation and protected areas. *Philos. Trans. R. Soc. B Biol. Sci.* **360**, 133–146 (2005).

22. Branch, T. A., Rutherford, K. & Hilborn, R. Replacing trip limits with individual transferable quotas: Implications for discarding. *Mar. Policy* **30**, 281–292 (2006).

23. Branch, T. A. & Hilborn, R. Matching catches to quotas in a multispecies trawl fishery: targeting and avoidance behavior under individual transferable quotas. *Can. J. Fish. Aquat. Sci.* **65**, 1435–1446 (2008).

24. Costello, C., Lynham, J., Lester, S. E. & Gaines, S. D. Economic Incentives and Global Fisheries Sustainability. *Annu. Rev. Resour. Econ.* **2**, 299–318 (2010).

25. Le Bris, A. *et al.* Climate vulnerability and resilience in the most valuable North American fishery. *Proc. Natl. Acad. Sci. U. S. A.* **115**, 1831–1836 (2018).

26. Costello, C. & Grainger, C. Property rights, regulatory capture, and exploitation of natural resources. *J. Assoc. Environ. Resour. Econ.* **5**, (2018).

27. Melnychuk, M. C. *et al.* Which design elements of individual quota fisheries help to achieve management objectives? *Fish Fish.* **17**, 126–142 (2016).

28. Essington, T. E. Ecological indicators display reduced variation in North American catch share fisheries. *Proc. Natl. Acad. Sci.* **107**, 754–759 (2010).

29. Essington, T. E. *et al.* Catch shares, fisheries, and ecological stewardship: A comparative analysis of resource responses to a rights-based policy instrument.

Conserv. Lett. **5**, 186–195 (2012).

30. Garcia, S. M., Ye, Y., Rice, J. & Charles, A. *Rebuilding of marine fisheries Part 1: Global review*. *FAO Fisheries and Aquaculture Technical Paper* (2018).

31. Verbeke, G. & Molenberghs, G. *Linear Mixed Models for Longitudinal Data*. (Springer-Verlag, 2009).

32. Shadish, W. R., Cook, T. D. C. & Campbell, D. T. *Quasi-Experimental Designs for Generalized Causal Inference*. (Houghton Mifflin, 2004).

33. Brooks, M. E. *et al.* glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *R J.* **9**, 378–400 (2017).

34. R Core Team. R studio. (2017).

35. Parkes, G. *et al.* The effects of catch share management on MSC certification scores. *Fish. Res.* **182**, 18–27 (2016).

Figures and tables

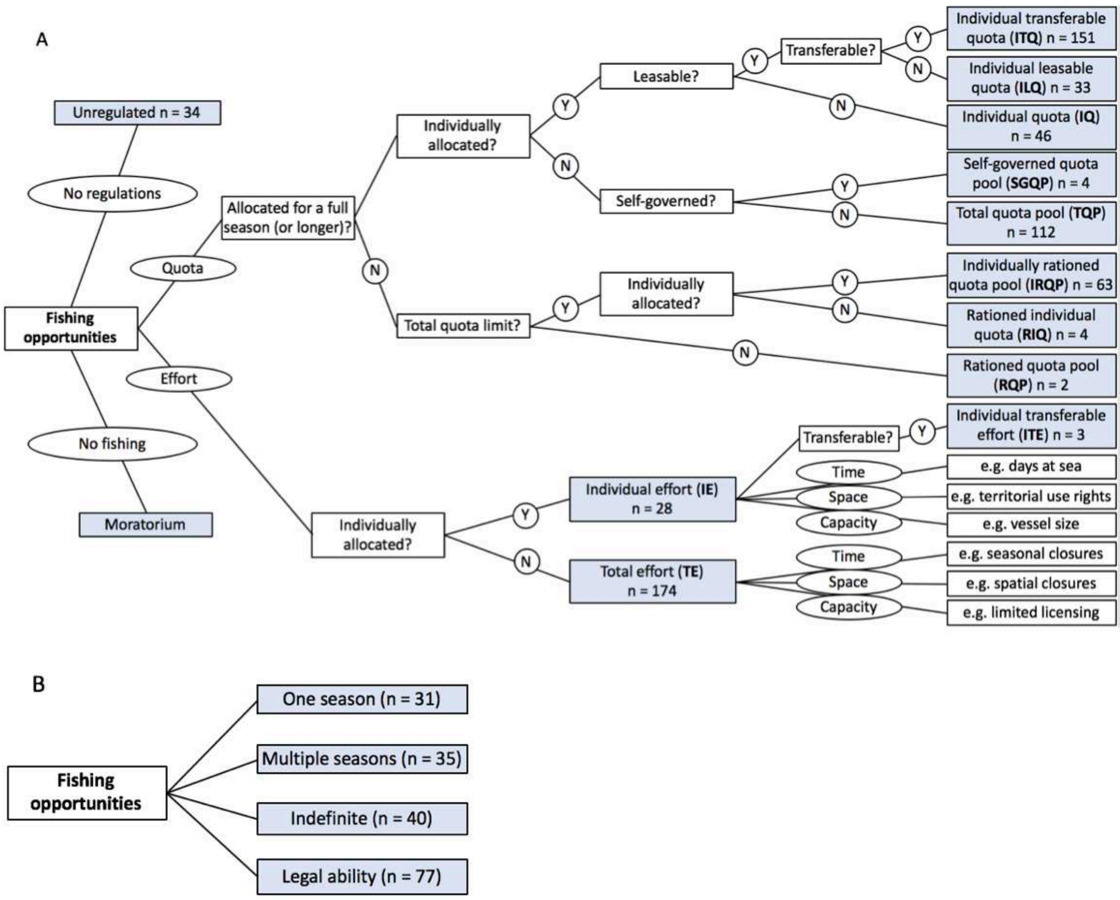

Figure 1. A) The classification decision tree for fisheries management systems based on their attributes. The dark-blue terms are the 12 exhaustive classifications used in this study. B) The classification decision tree for the duration of fishing opportunities. Definitions used for the classifications are recorded in Table A1. For each exhaustive classification the number of unique stocks and management classifications that occurred in the dataset are noted.

Table 1. Empirical research linking attributes of fisheries management systems to sustainable fishing.

Study	Coverage	Dependent variable	Method	Individual allocation	Transferability	Quota	Duration	Multiple attributes
[3]	11,153 fisheries, 1960–2003, 121 ITQs, global **,^^	Collapsed landings (binary)	Difference-in-differences	-	-	-	-	ITQ: Lower probability of collapse
[2]	20 ITQ stocks, global, from 16 to 36 years *,^	Biomass change	Descriptive	-	-	-	-	ITQ: Mixed effect
[24]	>11,000 fisheries, 1950–2003, 121 ITQs, global, **,^^	Collapsed landings (binary)	Difference-in-differences (subset)	-	-	Lower probability of collapse	-	IT: Lower probability of collapse
[28]	15 IQ/ITQ in North America *,^	Landings, mortality, biomass, habitat-damaging gear, discards, catch:quota	Before after control impact	-	-	-	-	IQ/ILQ/ITQ: Lower variability of mortality and biomass, no effect on mortality or biomass
[4]	345 stocks, global, 2000–2004 ***,^	Catch:quota, F:Ftarget, B:Btarget	1) Fixed-effects models, 2) mixed-	Lower catch:quota, lower probability	-	Lower mortality, no effect	-	IQ/ILQ/ITQ: Lower variability of catch:quota,

			effects models, 3) propensity score matching	of high overfishing		on biomass		lower mortality, no effect on biomass
29	84 IQ/ITQ and 140 reference fisheries ***,^	Landings, mortality, biomass	Difference-in-differences (Bayesian)	-	-	-	Lower variability of landings and mortality	IQ/ILQ/ITQ: Lower variability of landings and mortality, no effect on mortality or biomass
27	167 stocks, global, 2000-2004 ***,^	Catch:quota, F:Ftarget, B:Btarget	1) mixed-effects models 2) random forest models	No independent effect of exclusivity	Lower biomass	-	No effect	-
35	298 MSC-certified fisheries, 170 ITQ/IQ/TURF fisheries, 136 which are "SET" ****, ^^	MSC certification scores (includes stock assessments)	1) Bayesian belief networks, 2) statistical association	-	-	-	-	IQ/ILQ/ITQ/TURF: Higher probability of high MSC score for stock assessment
26	178 fisheries, 27 countries. 78 transition to	Mortality	1) Regression, 2) non-	-	-	-	-	IQ/ILQ/ITQ/TURF: Lower mortality on

	ITQ/IQ/TURF ***,^^		parametric approach					overexploited stocks, no effect on others
15	ITQ/IQ/TURF **,***,^^	Collapsed (binary)	1) Difference-in-differences 2) Instrumental variable	-	Lower probability of collapse			IQ/ILQ/ITQ/TURF: Lower probability of collapse

Biological data

* Manual

** Sea Around Us database (http://www.seaaroundus.org/)

*** RAM legacy database (https://www.ramlegacy.org/)

**** MSC fisheries database

Classification data

^ Manual

^^ EDF catch share database (http://fisherysolutionscenter.edf.org/database)

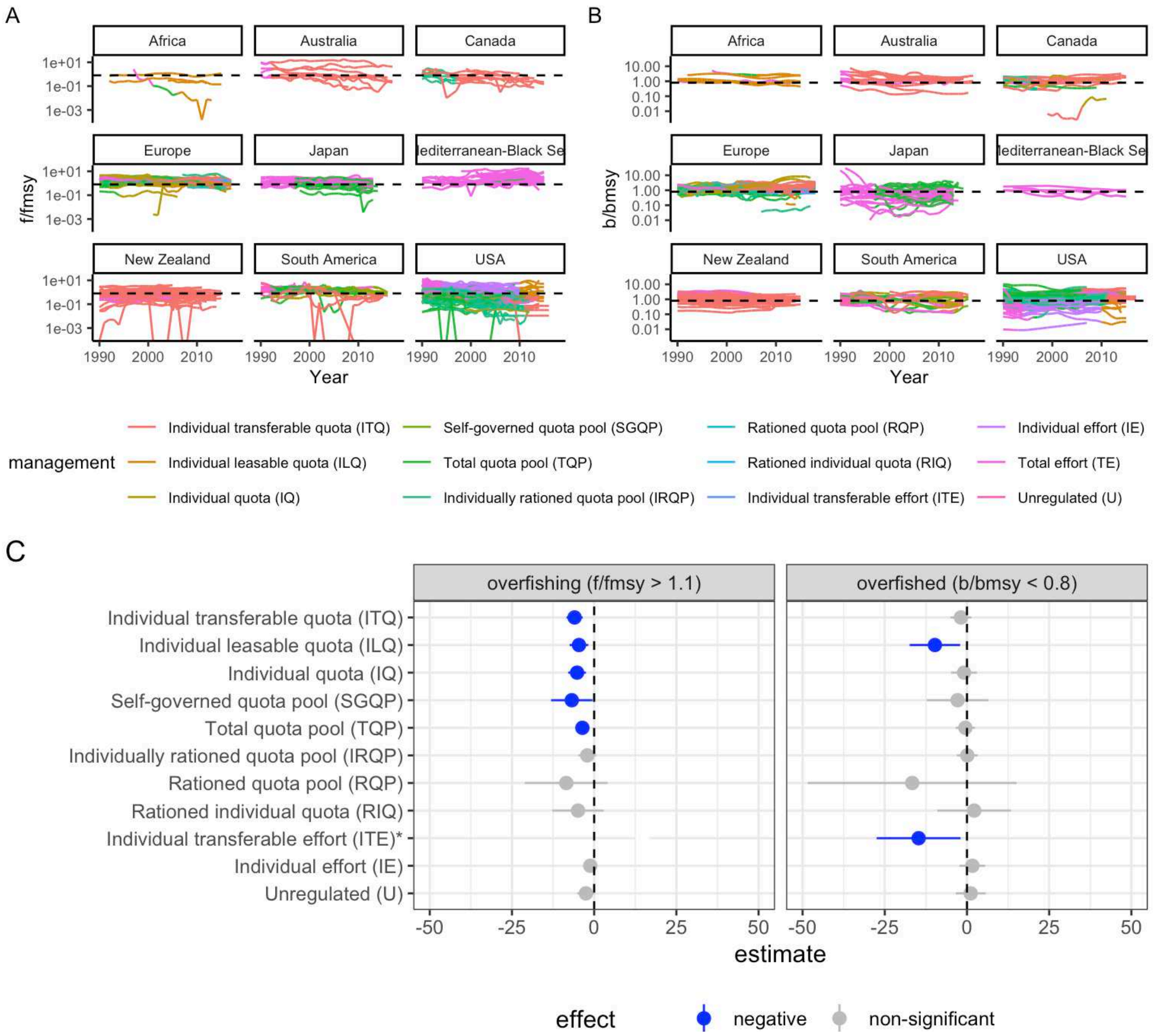

Figure 2. A) F/F_{msy} for all classified fisheries management systems (dotted line indicates the threshold for *overfishing,* i.e., when F/F_{msy} = 1.1. B). B/B_{msy} for all classified fisheries management systems (dotted line indicates the threshold for *overfished,* i.e., when B/B_{msy} = 0.8). C) Estimates and 95 percent confidence intervals of management systems compared to TE. Negative (blue) values indicate that the management system reduces the probability of the outcome variable, for example IQ reduces the probability of overfishing compared to TE. The non-significant effect for ITE cannot be displayed in the figure due to wide standard errors (Table B1).

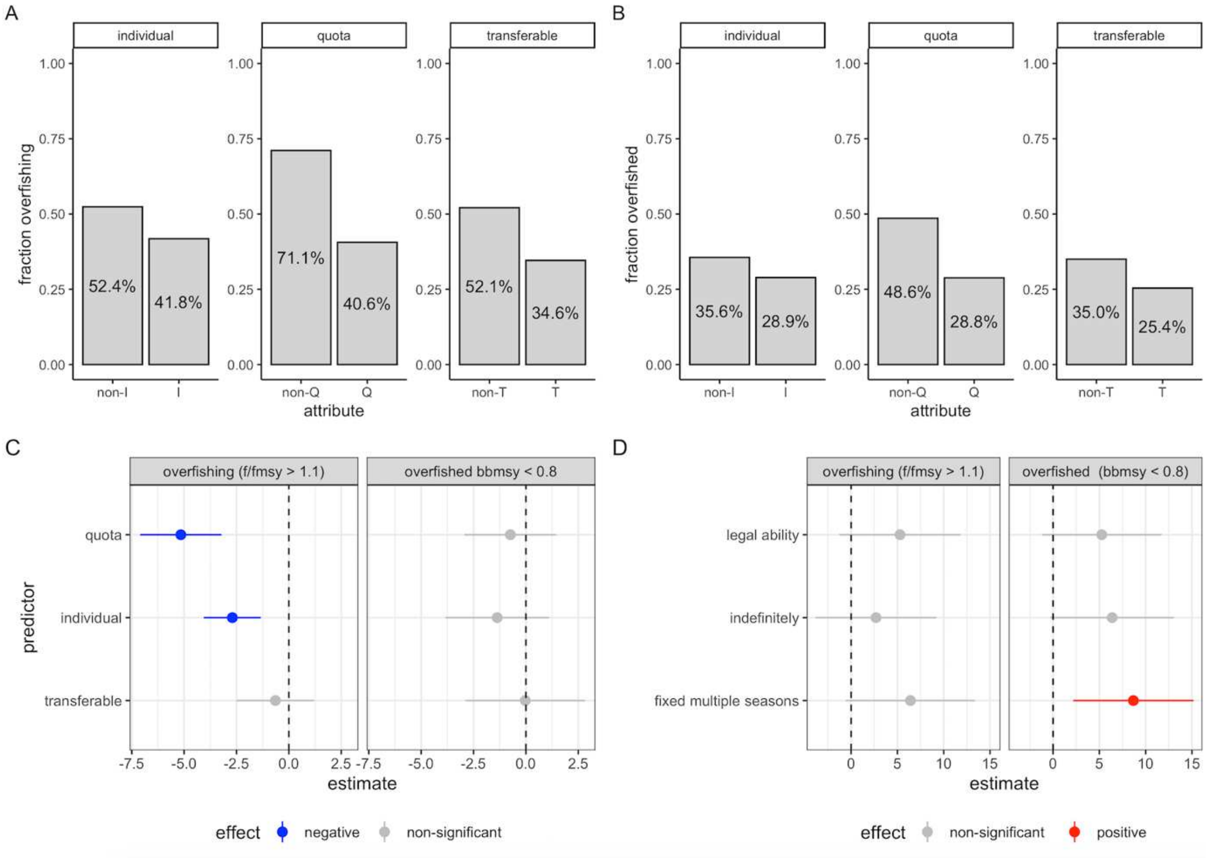

Figure 3. A) frequency of overfishing ($F/F_{msy} > 1.1$) and B) frequency of overfished observations ($B/B_{msy} < 0.8$) for the attributes I, T, and Q. Each observation is a stock-year combination. C) Mixed-effects results for the attributes I, T, and Q. Negative (blue) effects indicate a reduced probability of overfishing for I and Q (overfishing: 343 stocks with 6803 observations; overfished: 299 stocks with 6875 observations). D) Effects for the duration of fishing opportunities compared to a single season. The positive (red) value indicates an increased probability of the overfished state for fixed multiple seasons.

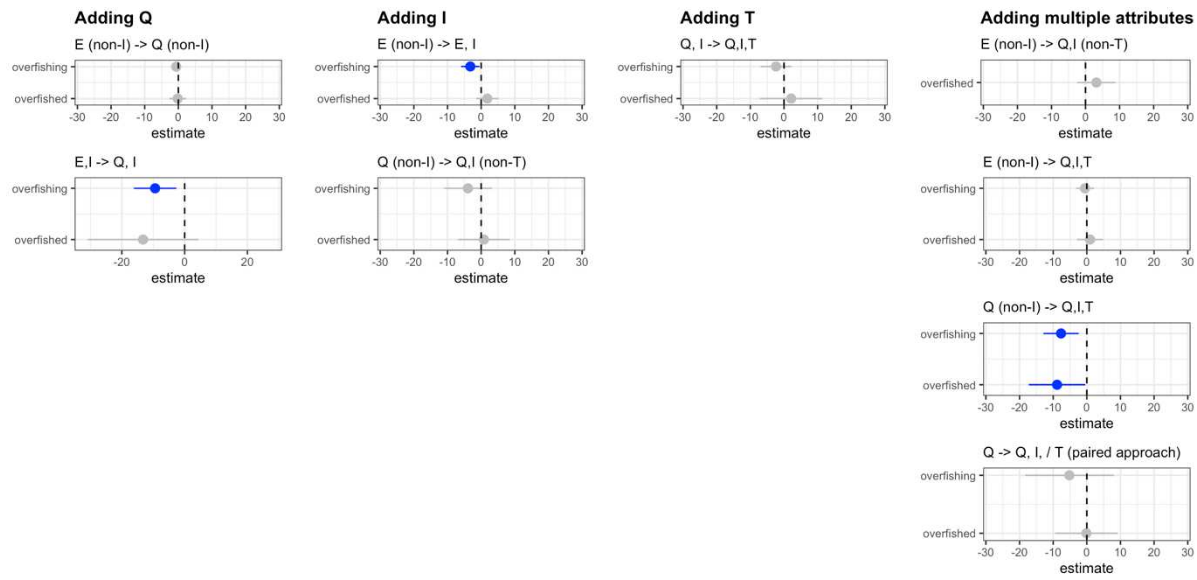

Figure 4. DiD estimates of treatment effects, outcomes for the probability of *overfishing* and *overfished* outcomes. DiD estimates are indicated for the addition of Q (TE systems transitioning to pooled quota systems, IE systems transitioning to individual quota systems), I (TE systems transitioning to IE, pooled quota systems transitioning to individual (non-transferable) quota systems, T (individual quota systems transitioning to ITQ systems), and multiple attributes simultaneously. Negative (blue) values indicate that the attribute reduced the probability of the outcome variable.

Appendix A. Management system definitions and DiD pairs

Table A1: Management system definitions, for the 12 final management systems and the 4 types of duration of harvesting rights.

Management system	**Definition**
Individual Transferable Quota	A quantity limit on catches/landings is allocated for the exclusive use of a vessel/license and can be sold to a different vessel/license (quota swapping and leasing may also be permitted).
Individual Leasable Quota	A quantity limit on catches/landings is allocated for the exclusive use of a vessel/license and can be sold to a different vessel/license for a fixed time period only (quota swapping may also be permitted but permanent transfer is not).
Individual Quota	A quantity limit on catches/landings is allocated for the exclusive use of a vessel/license and can be swapped for other quota but cannot be leased or permanently sold (i.e. monetary transfers).
Self-Governed Quota Pool(s)	A quantity limit on catches/landings is allocated to a group of vessels/licenses for joint use. The pool is managed by its membership. Fishers have no individual holdings to enter/exit the pool.
Total Quota Pool	A quantity limit on catches/landings is allocated to a group of vessels/licenses for joint use. The pool is managed by the government.
Individually-Rationed Quota Pool	A quantity limit on catches/landings is allocated to a group of vessels/licenses for joint use. These limits are allocated to individual vessels/licenses for exclusive use in multiple time periods within a fishing season (e.g. daily, weekly or monthly limits).
Rationed Quota Pool	A quantity limit on catches/landings is allocated to a group of vessels/licenses for joint use. These limits are administered in multiple time periods within a fishing season (e.g. weekly or monthly vessel limits).
Rationed Individual Quota	A quantity limit on catches/landings is allocated for the exclusive use of a vessel/license. These limits are administered in multiple time periods within a fishing season (e.g. weekly or monthly vessel limits). There is no total quota limit that can be reached, meaning there is no pool and each vessel/license limit is independent.
Individual Transferable Effort	A limit on fisheries inputs (e.g. days at sea, area/territory, vessel capacity) is allocated for the exclusive use of a vessel/license and can be sold to a different vessel/license.
Individual Effort	A limit on fisheries inputs (e.g. days at sea, area/territory, vessel capacity) is allocated for the exclusive use of a vessel/license.
Total Effort	A limit on fisheries inputs (e.g. number of vessels, days at sea, vessel capacity, seasonal closure, spatial closure) is set for the entire fishery.
Unregulated	There is no fisheries legislation limiting the amount of fishing pressure.
Duration	**Definition**
Indefinite	In fisheries legislation it is specified that fishing opportunities are held permanently. The size of the fishing opportunity may change as the total changes (e.g. 3% of 100 may become 3% of 150), but fishing opportunity does not change as a relative share of the total. Fishing licenses may be subject to change at a different interval.
Fixed multiple seasons	In fisheries legislation it is specified that fishing opportunities are held for a fixed period that spans multiple fishing seasons (e.g. 10 years) after which the relative shares of fishing opportunities may be revised. Fishing licenses may be subject to change at a different interval.
One season	In fisheries legislation it is specified that fishing opportunities are held for one season (e.g. one year) after which the relative shares of fishing opportunities may be revised. Fisheries legislation requires an active decision each year on allocations (i.e. the default is not

	necessarily the same allocation as the previous year). Fishing licenses may be subject to change at a different interval.
Legal ability	In fisheries legislation it is specified that the fisheries manager reserves the right to revise the relative shares of fishing opportunities, but as the duration of the fishing opportunities is not specified this can take place at any time. Fisheries legislation does not require an active decision each year on allocations (i.e. the default is the same allocation as the previous year). Fishing licenses may be subject to change at a different interval.

Table A2: Treatment and control stocks for paired difference in difference analysis.

Treatment/ control	**Did code**	**stock name RAM**	**year of quota**	**year of IQ**	**minimum year used**	**final year used**
impact	sa1	Sablefish Eastern Bering Sea / Aleutian Islands / Gulf of Alaska	1977	1995	1982	2011
control	sa1	Sablefish Pacific Coast	1982	2011	1982	2011
impact	sa2	Sablefish Pacific Coast of Canada	1981	1990	1982	2011
control	sa2	Sablefish Pacific Coast	1982	2011	1982	2011
impact	gh1	Greenland halibut NAFO 4RST	1982	1995	1986	2017
control	gh1	Greenland halibut Bering Sea and Aleutian Islands	1986	no IQ	1986	2017
impact	wp1	Walleye pollock Eastern Bering Sea	1977	2000	1982	2017
control	wp1	Walleye pollock Gulf of Alaska	1977	no IQ	1982	2017
impact	wp2	Walleye pollock Aleutian Islands	1980	2000	1982	2017
control	wp2	Walleye pollock Gulf of Alaska	1977	no IQ	1982	2017
impact	pc1	Pacific cod West Coast of Vancouver Island	1979	1997	1982	2008
control	pc1	Pacific cod Bering Sea	1977	2008	1982	2008
impact	pc2	Pacific cod Hecate Strait	1992	1997	1992	2008
control	pc2	Pacific cod Bering Sea	1977	2008	1992	2008
impact	tf1	Tilefish Mid-Atlantic Coast	2001	2009	1994	2017
control	tf1	Tilefish Southern Atlantic coast	1994	no IQ	1994	2017
impact	tf2	Tilefish Gulf of Mexico	2004	2010	1994	2017
control	tf2	Tilefish Southern Atlantic coast	1994	no IQ	1994	2017
impact	rkc1	Red king crab Bristol Bay	1980	2005	1982	2015
control	rkc1	Red king crab Norton Sound	1978	no IQ	1982	2015
impact	pop1	Pacific Ocean perch West Coast of Vancouver Island	1979	1997	1982	2011
control	pop1	Pacific ocean perch Pacific Coast	1982	2011	1982	2011
impact	ha_ar	Argentine hake Southern Argentina	1998	2010	1998	2017
control	ha_ar	Argentine hake Northern Argentina	1998	no IQ	1998	2017

impact	lob1	Norway lobster Labadie, Jones and Cockburn (FU 20-21)	1980	1997	1982	2009
control	lob1	Norway lobster Smalls (FU 22)	1980	no IQ	1982	2009
impact	lob2	Norway lobster ICES 8ab	1980	1997	1982	2017
control	lob2	Norway lobster Smalls (FU 22)	1980	no IQ	1982	2017
impact	ac1	Atlantic cod Northeast Arctic	1977	1990	1985	2017
control	ac1	Atlantic cod NAFO 1f and ICES 14	1985	no IQ	1985	2017
impact	ac2	Atlantic cod North-East Arctic (Norwegian coastal waters)	1977	1990	1985	2017
control	ac2	Atlantic cod NAFO 1f and ICES 14	1985	no IQ	1985	2017
impact	sna1	Red snapper Gulf of Mexico	1990	2010	2006	2017
control	sna1	Vermilion snapper Southern Atlantic coast	2006	no IQ	2006	2017
impact	nr1	Northern rockfish Gulf of Alaska	1980	2007	1980	2017
control	nr1	Northern rockfish Bering Sea and Aleutian Islands	1980	no IQ	1980	2017
impact	pop2	Pacific ocean perch Gulf of Alaska	1980	2007	1983	2011
control	pop2	Pacific ocean perch Pacific Coast	1983	2011	1983	2011
impact	pop3	Pacific ocean perch Haida Gwaii	1980	2007	1983	2011
control	pop3	Pacific ocean perch Pacific Coast	1983	2011	1983	2011
impact	rs1	Rock sole Hecate Strait	1980	1997	1982	2007
control	rs1	Northern rock sole Eastern Bering Sea and Aleutian Islands	1980	2007	1982	2007
impact	rs2	Rock sole Queen Charlotte Sound	1980	1997	1982	2007
control	rs2	Northern rock sole Eastern Bering Sea and Aleutian Islands	1980	2007	1982	2007

Appendix B. Additional tables and figures and sensitivity analyses

Table B1: Effect sizes, confidence intervals and p-values for the management system model (presented in Figure 2 in the main text). Bolded values are significant at the p<0.05 level.

Outcome variable	Management	estimate	upper CI	lower CI	probability
overfishing (f/fmsy > 1.1)	**ITQ**	**-5.96**	**-3.50**	**-8.42**	**<0.001**
	ILQ	**-4.62**	**-1.79**	**-7.45**	**0.001**
	IQ	**-5.20**	**-2.49**	**-7.91**	**<0.001**
	SGQP	**-6.81**	**-0.52**	**-13.10**	**0.03**
	TQP	**-3.58**	**-1.73**	**-5.43**	**<0.001**
	IRQP	-2.11	0.57	-4.78	0.12
	RIQ	-4.91	2.91	-12.73	0.22
	RQP	-8.49	4.09	-21.06	0.19
	ITE	14.70	4603.40	-4574.01	0.99
	IE	-1.19	0.90	-3.28	0.26
	unregulated	-2.51	0.10	-5.12	0.06
overfished (b/bmsy < 0.8)	ITQ	-1.85	1.34	-5.05	0.26
	ILQ	**-9.76**	**-2.09**	**-17.44**	**0.01**
	IQ	-0.89	3.05	-4.83	0.66
	SGQP	-2.85	6.51	-12.21	0.55
	TQP	-0.50	2.42	-3.42	0.74
	IRQP	0.10	3.26	-3.06	0.95
	RIQ	2.19	13.38	-9.01	0.70
	RQP	-16.66	15.09	-48.41	0.30
	ITE	-14.71	-1.95	-27.46	0.02
	IE	1.64	5.51	-2.24	0.41
	unregulated	1.13	5.66	-3.41	0.63

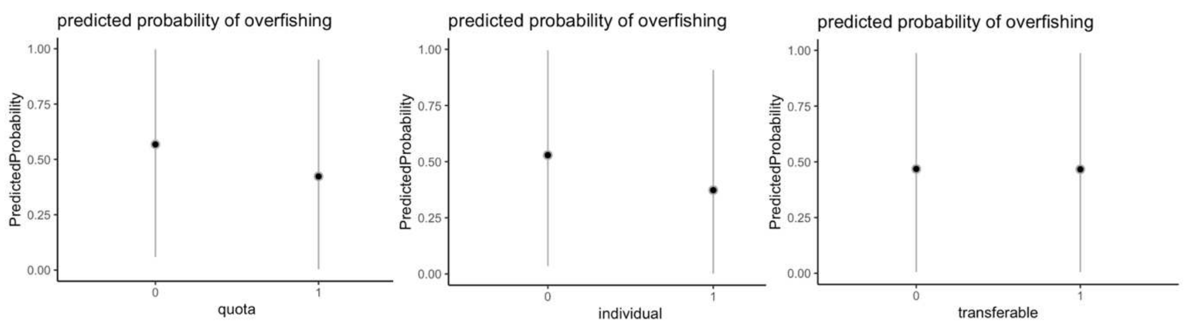

Figure B1: Predicted probabilities of overfishing with without (0) and with (1) quota, individual and transferable attributes.

Table B2: Effect sizes, confidence intervals and p-values for the management system model, sensitivity using fishing mortality and biomass trends. Bolded values are significant at the p<0.05 level.

Outcome variable	Management	estimate	upper CI	lower CI	probability
decreasing overfishing (f/fmsy > 1.1)	**ITQ**	**-0.89**	**-0.17**	**-1.61**	**0.02**
	ILQ	-0.97	0.03	-1.98	0.06
	IQ	-0.71	0.15	-1.57	0.11
	SGQP	-0.47	1.62	-2.55	0.66
	TQP	**-0.65**	**-0.04**	**-1.26**	**0.04**
	IRQP	-0.05	0.77	-0.88	0.90
	RIQ	0.62	3.30	-2.05	0.65
	RQP	-0.48	2.41	-3.36	0.75
	ITE	-0.46	1.19	-2.10	0.59
	IE	**0.81**	**1.60**	**0.02**	**0.04**
	unregulated	0.33	1.51	-0.85	0.59
Decreasing overfished (b/bmsy < 0.8)	ITQ	0.44	2.36	-1.49	0.66
	ILQ	-0.23	3.22	-3.67	0.90
	IQ	-0.22	2.98	-3.42	0.89
	SGQP	2.90	8.78	-2.99	0.33
	TQP	-0.04	2.03	-2.10	0.97
	IRQP	1.81	4.03	-0.41	0.11
	RIQ	-12.26	9556.46	-9580.98	1.00
	RQP	-10.22	3244.54	-3264.97	1.00
	ITE	-0.57	4.88	-6.02	0.84
	IE	0.78	3.27	-1.71	0.54
	unregulated	0.60	7.23	-6.04	0.86

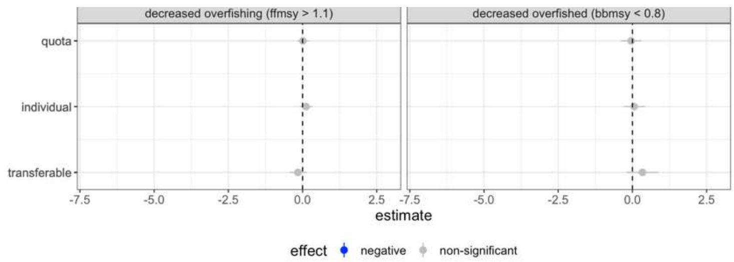

Figure B2: Mixed-effects results for the attributes I, T, and Q predicting positive trends in stocks with *overfishing* (decreased overfishing) or *overfished* stocks (decreased overfished).

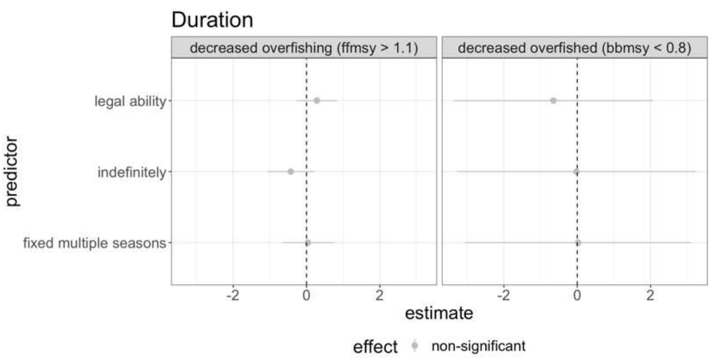

Figure B3: Mixed-effects results for different duration of IQ's predicting positive trends in stocks with *overfishing* (decreased overfishing) or *overfished* stocks (decreased overfished).

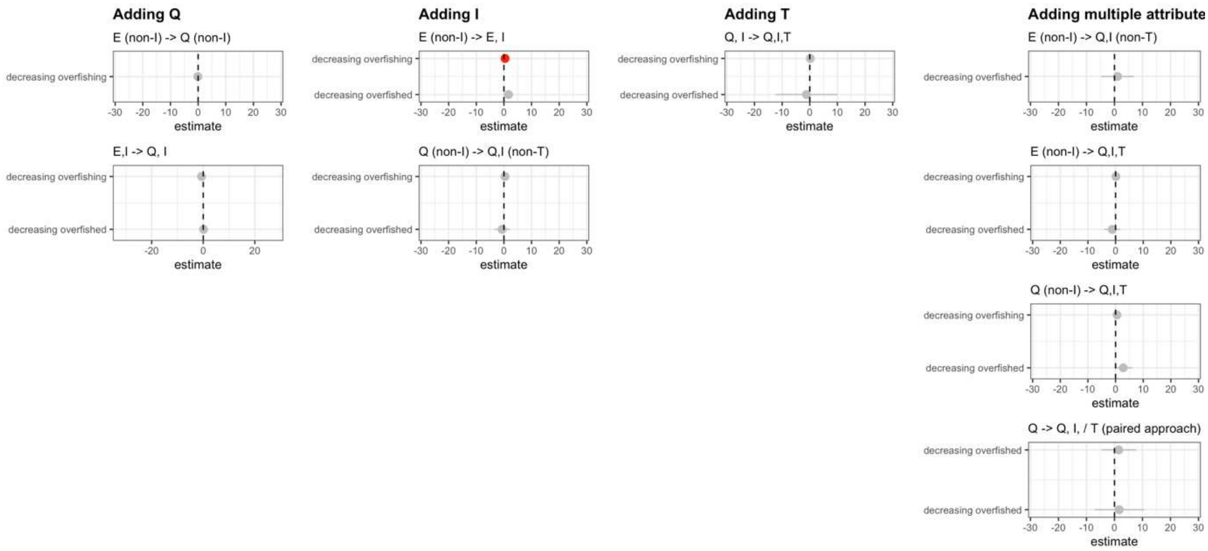

Figure B4: DiD estimates of treatment effects, outcomes for the probability of *decreasing overfishing* and *decreasing overfished* outcomes. DiD estimates are indicated for the addition of Q (TE systems transitioning to pooled quota systems, IE systems transitioning to individual quota systems), I (TE systems transitioning to IE, pooled quota systems transitioning to individual (non-transferable) quota systems, T (individual quota systems transitioning to ITQ systems), and multiple attributes simultaneously. Positive (red) values indicate that the attribute increased the probability of the outcome variable.

Table B3: Effect sizes and standard errors, confidence intervals and p-values for the management system model, sensitivity predicting high overfishing and high overfished. Bolded values are significant at the p<0.05 level.

Outcome variable	Management	estimate	upper CI	lower CI	probability
High overfishing (F/fmsy >1.5)	**ITQ**	**-12.16**	**-7.32**	**-16.99**	**<0.001**
	ILQ	**-11.53**	**-6.18**	**-16.88**	**<0.001**
	IQ	**-11.59**	**-6.30**	**-16.88**	**<0.001**
	SGQP	**-12.51**	**-2.86**	**-22.16**	**0.01**
	TQP	**-10.76**	**-6.32**	**-15.20**	**<0.001**
	IRQP	**-11.42**	**-6.47**	**-16.38**	**<0.001**
	RIQ	-1.93	9.56	-13.43	0.74
	RQP	-8.26	1.73	-18.26	0.11
	ITE	1.59	11.16	-7.97	0.74
	IE	**-7.24**	**-3.04**	**-11.44**	**<0.001**
	unregulated	**-6.43**	**-1.58**	**-11.28**	**0.01**

High overfished (b/bmsy < 0.5)	ITQ	0.51	4.88	-3.86	0.82
	ILQ	-1.68	6.11	-9.48	0.67
	IQ	0.17	6.18	-5.85	0.96
	SGQP	-0.37	8.51	-9.24	0.94
	TQP	1.58	5.44	-2.29	0.42
	IRQP	2.37	6.84	-2.11	0.30
	RIQ	-10.80	7815.90	-7837.51	1.00
	RQP	-12.14	14377.87	-14402.15	1.00
	ITE	-1.24	15.11	-17.58	0.88
	IE	**5.65**	**9.87**	**1.42**	**0.01**
	unregulated	2.35	7.84	-3.13	0.40

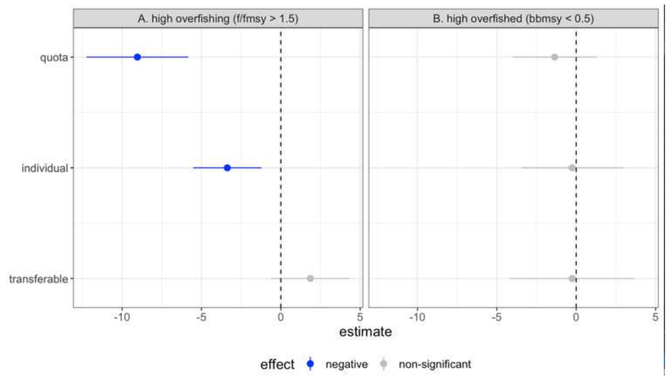

Figure B5: Mixed-effects results for the attributes I, T, and Q. Negative (blue) effects indicate a reduced probability of overfishing for I and Q for *high overfishing* and *highly overfished*.

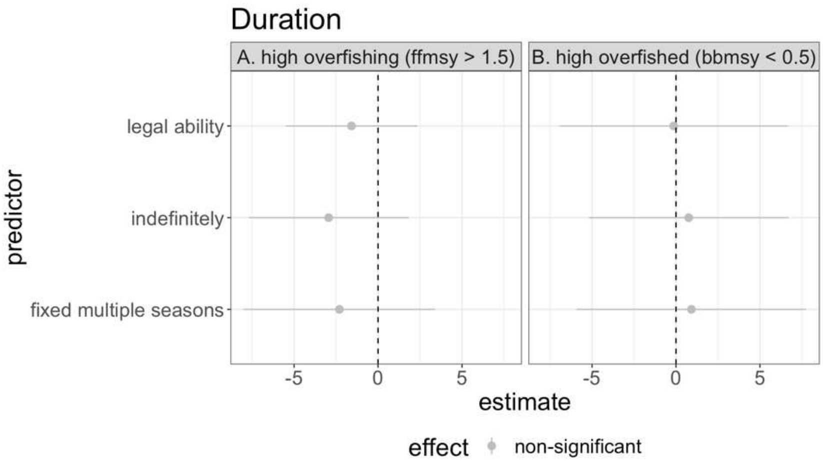

Figure B6: Mixed-effects results for different duration of IQ's for *high overfishing* and *highly overfished*.

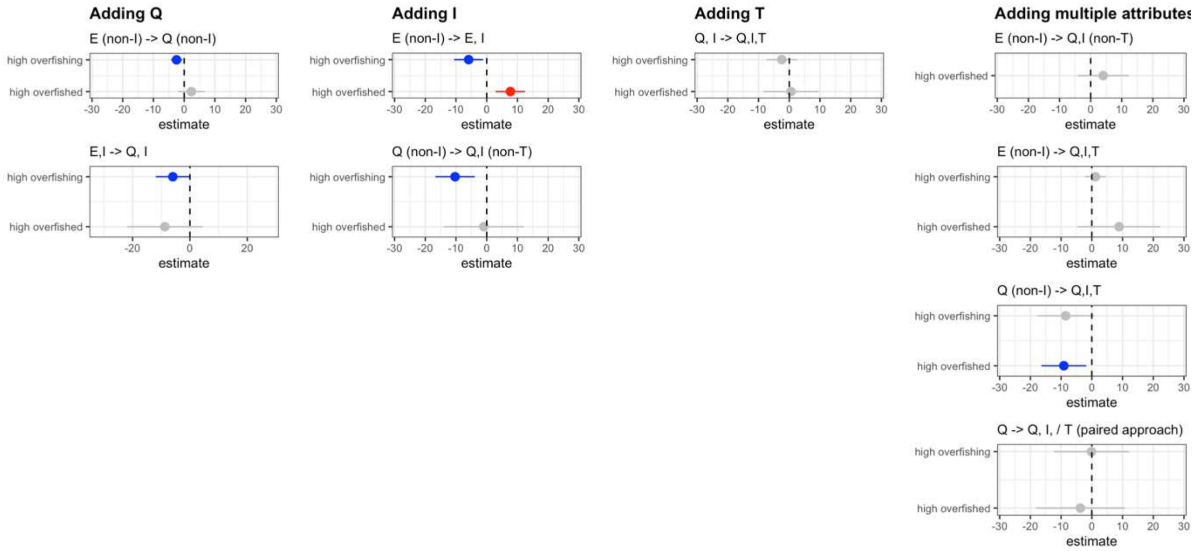

Figure B7: DiD estimates of treatment effects, outcomes for the probability of *high overfishing* and *high overfished* outcomes. DiD estimates are indicated for the addition of Q (TE systems transitioning to pooled quota systems, IE systems transitioning to individual quota systems), I (TE systems transitioning to IE, pooled quota systems transitioning to individual (non-transferable) quota systems, T (individual quota systems transitioning to ITQ systems), and multiple attributes simultaneously. Negative (blue) values indicate that the attribute reduced the probability of the outcome variable.

Figures

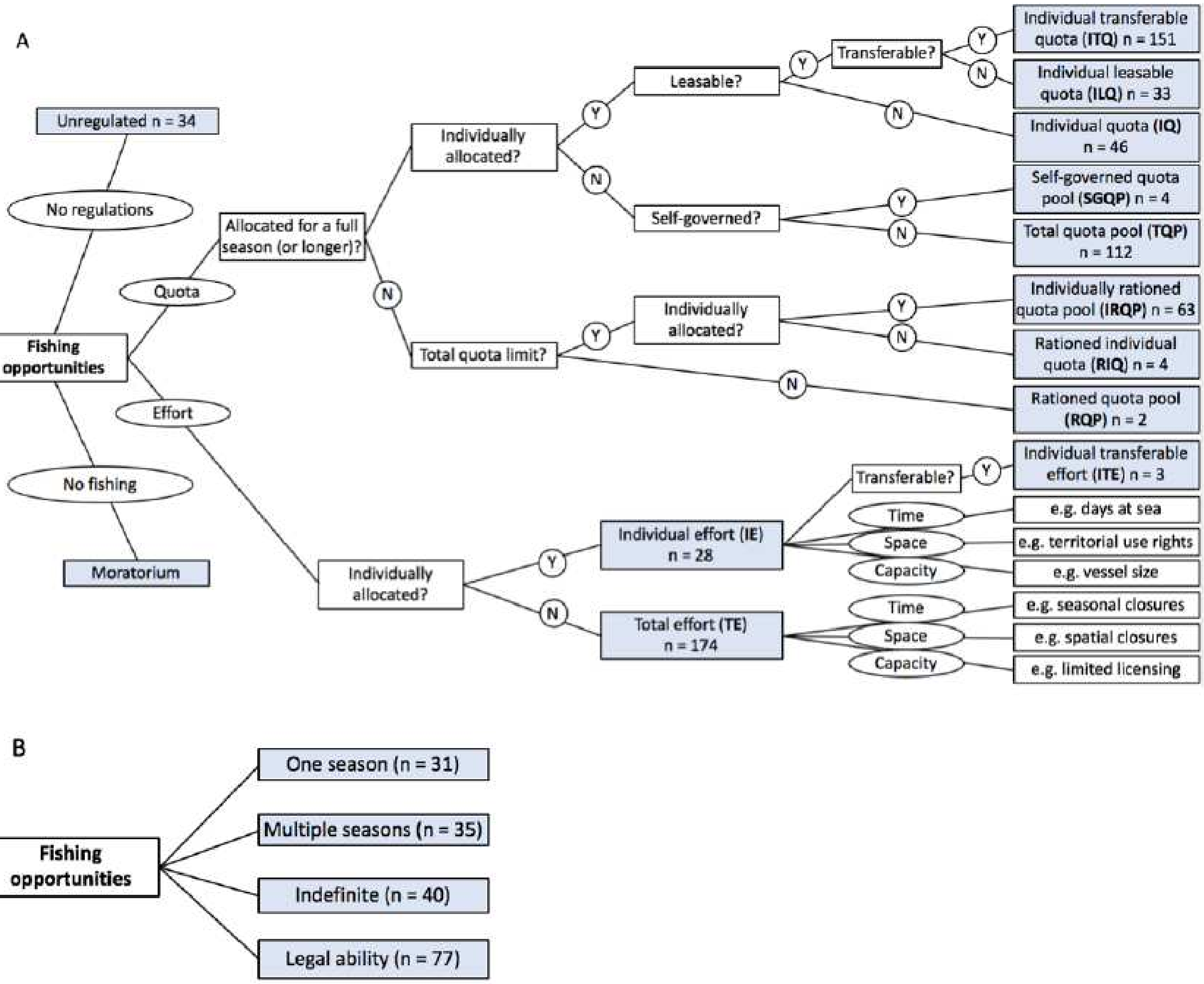

Figure 1

A) The classification decision tree for fisheries management systems based on their attributes. The dark-blue terms are the 12 exhaustive classifications used in this study. B) The classification decision tree for the duration of fishing opportunities. Definitions used for the classifications are recorded in Table A1. For each exhaustive classification the number of unique stocks and management classifications that occurred in the dataset are noted.

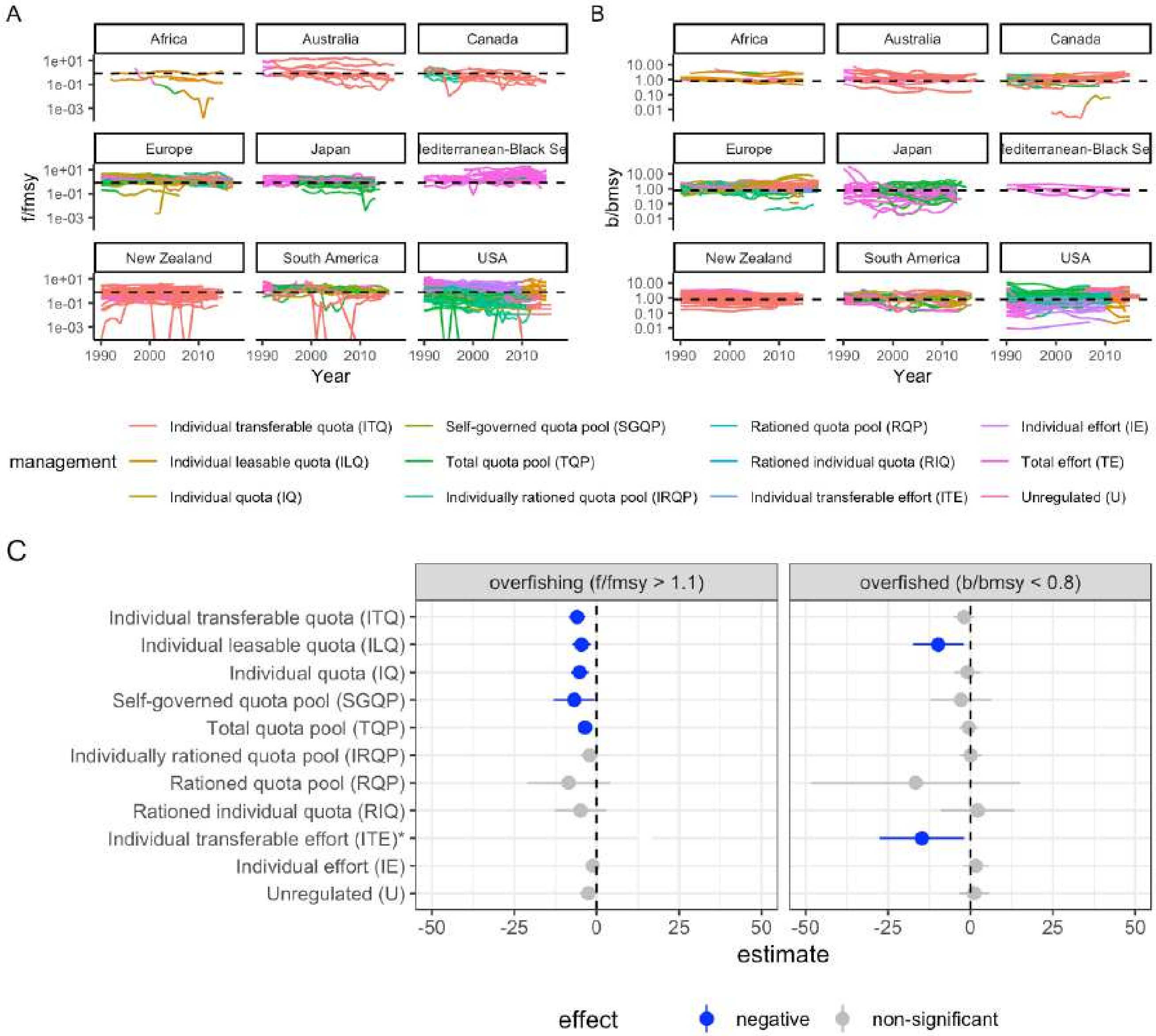

Figure 2

A) F/Fmsy for all classified fisheries management systems (dotted line indicates the threshold for overfishing, i.e., when F/Fmsy = 1.1. B). B/Bmsy for all classified fisheries management systems (dotted line indicates the threshold for overfished, i.e., when B/Bmsy = 0.8). C) Estimates and 95 percent confidence intervals of management systems compared to TE. Negative (blue) values indicate that the management system reduces the probability of the outcome variable, for example IQ reduces the probability of overfishing compared to TE. The non-significant effect for ITE cannot be displayed in the figure due to wide standard errors (Table B1).

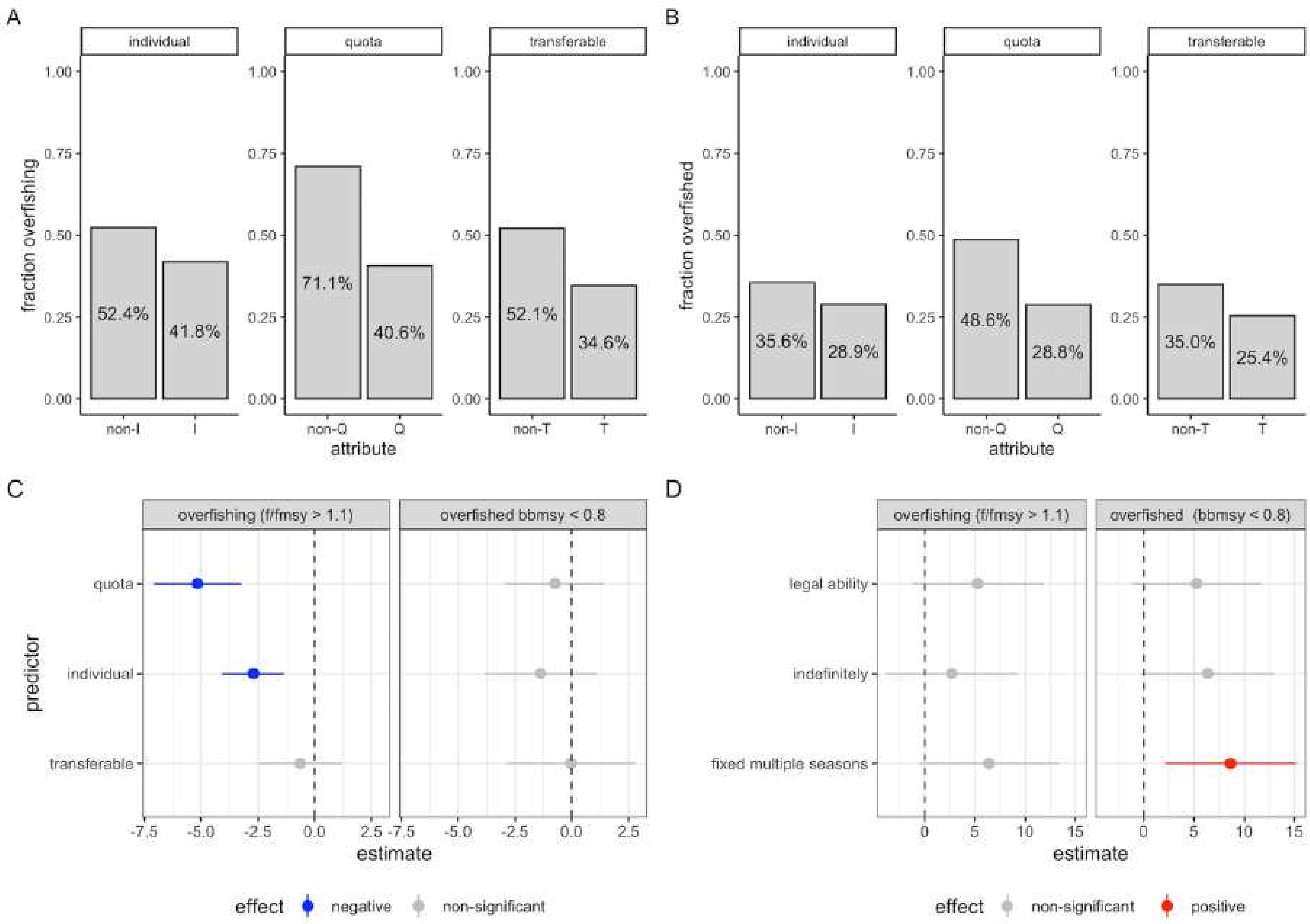

Figure 3

A) frequency of overfishing (F/Fmsy >1.1) and B) frequency of overfished observations (B/Bmsy < 0.8) for the attributes I, T, and Q. Each observation is a stock-year combination. C) Mixed effects results for the attributes I, T, and Q. Negative (blue) effects indicate a reduced probability of overfishing for I and Q (overfishing: 343 stocks with 6803 observations; overfished: 299 stocks with 6875 observations). D) Effects for the duration of fishing opportunities compared to a single season. The positive (red) value indicates an increased probability of the overfished state for fixed multiple seasons.

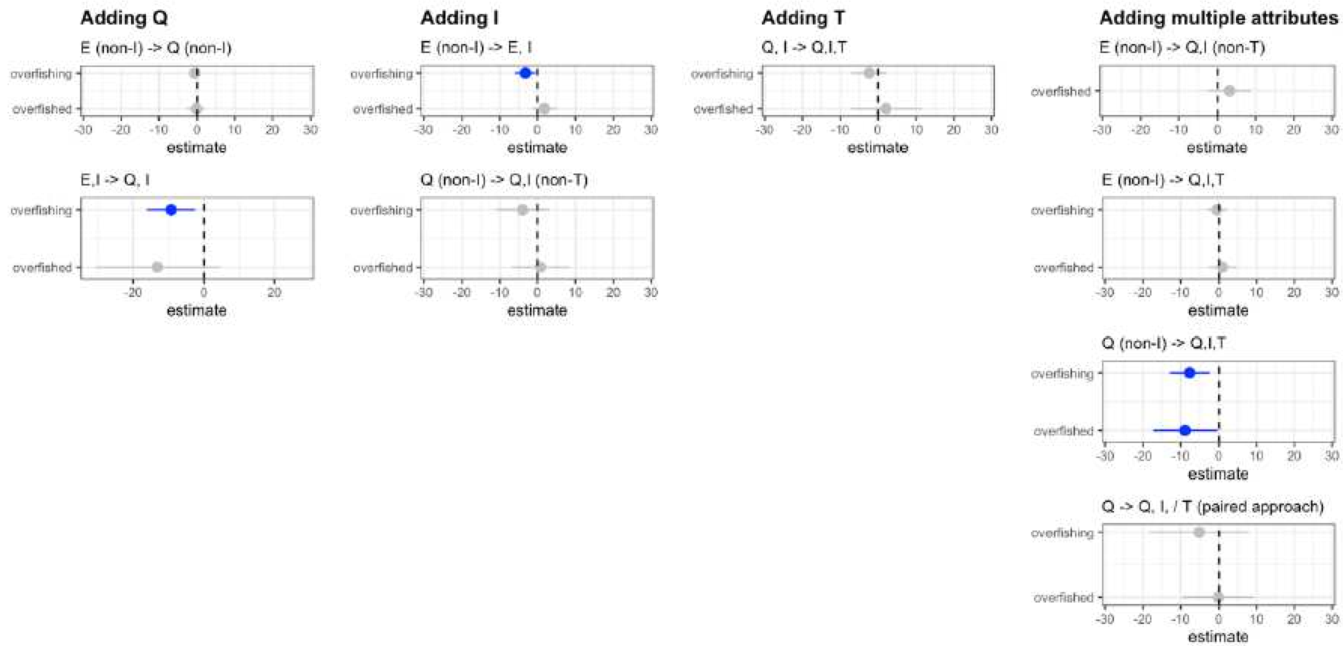

Figure 4

DiD estimates of treatment effects, outcomes for the probability of overfishing and overfished outcomes. DiD estimates are indicated for the addition of Q (TE systems transitioning to pooled quota systems, IE systems transitioning to individual quota systems), I (TE systems transitioning to IE, pooled quota systems transitioning to individual (non-transferable) quota systems, T (individual quota systems transitioning to ITQ systems), and multiple attributes simultaneously. Negative (blue) values indicate that the attribute reduced the probability of the outcome variable.