Protecting the oceans: Marine conservation efforts and their effects on industrial fishing

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Abstract

I evaluate the effect of Marine Protected Areas (MPAs) on industrial fishing globally. Using comprehensive data on global fishing and spatial regression discontinuity methods, I estimate the causal effect of MPAs on industrial fishing effort. My main result indicates that protected areas with a stricter protection designation significantly reduce fishing efforts. I find that, on average, fishing efforts have been reduced by 30.5% of the total hours of fishing per km^2 globally, between 2016 - 2020. I also find a concentration of fishing activity just inside of the border of some protected areas, suggesting strategic behavior by vessels, especially in MPAs with no designation and no clear restriction designation.

Key words: Marine protected areas, Fishing efforts, Industrial fishing activity, Spatial regression discontinuity.
JEL Classification: Q22,Q25, C31

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1 Introduction

Marine Protected Areas (MPAs) are areas with geographical boundaries within which limits are imposed on environmental exploitation activities. Currently, there are 28.1 million km^2 of coastal and oceanic waters protected and conserved, which represent 7.74% of the oceans. The objective of these areas is to achieve the long-term conservation of nature with associated ecosystem services and cultural values, through the restriction of activities. Despite the conservation efforts associated with the declaration of protected areas, knowledge about their effectiveness in controlling environmental exploitation activities is limited.

One third of the world's fishing is carried out by industrial level vessels (FAO, 2020).Given their size and extension, if not regulated, this type of activity will have a significant and negative impact on local food production; the livelihoods of communities; and especially, on biodiversity in maritime ecosystems. Considering that the dynamics and extension of industrial fishing is complex, the mere existence of protected areas does not guarantee their effectiveness in controlling the fishing efforts which take place within them. The lack of compliance with the restriction of this level of fishing activity in the MPAs may jeopardize the conservation objectives of these areas (Komoroske and Lewison, 2015). It is, therefore, essential to study the behavior of this type of fishing within the framework of protected areas, in order to better understand how marine protected areas should be designed, implemented, monitored, and controlled.

The evidence has indicated that the effectiveness of MPAs in the conservation of ecosystems, in ecological terms, is determined by a set of factors that are differential around the world. In particular contexts, empirical evidence has found that the effectiveness of protected areas varies according to the ease of access to them (Edgar et al., 2014, Advani et al., 2015), and the degree of efficiency of the administration and supervision of protected areas

(Petrossian, 2015, Weekers et al., 2019). This effectiveness is also influenced by factors such as their age and size (Malcolm et al., 2015); the extent and type of ecosystem (Miller and Russ, 2014); and the type of regulation on the activities allowed within the limits of these areas (Edgar et al., 2014).

The results of studies in the related literature are not conclusive. These evaluate the effectiveness of specific protected areas in controlling fishing efforts locally; that is, considering particular cases of protected areas. Global-level studies of this dynamic are necessary if we are to reach conclusions with sufficient representativeness of MPAs. This will contribute to the discussion on the relationship between protected areas and the control of unauthorized industrial fishing activity beyond specific cases. In this article, I assess the effectiveness of MPAs in controlling industrial fishing activity with high-resolution information on global fishing efforts. Specifically, of the 17,448 MPAs that exist around the world, I evaluate 434 MPAs, which are those created before 2016, that are fully marine; that is, that they have no contact with land areas (coastal protected areas), and that are managed by national governments. Although it is not possible to analyze all the marine protected areas, to the best of my knowledge, this is the first study that analyzes the relationship between MPAs and industrial fishing activity involving a large number of MPAs and with global coverage.

In this work, I focus on evaluating the effect of MPAs on industrial fishing activity. Although I do not consider the ecological and/or environmental impacts, I assume that a reduction in fishing efforts translates into lower catch indicators; better fish production; and therefore, better quality of the ecosystem (Hilborn et al., 2020). The general sense of the investigation is in the evaluation of whether the fishing efforts are being reduced within marine protected areas; that is, whether industrial fishing is, in fact, being controlled in areas where it is prohibited.

I estimate the causal effect of MPAs on the number of hours of industrial fishing activity around the world using a non-parametric spatial regression discontinuity model, following the model proposed by Calonico et al. (2014). The identification strategy consists of comparing cells just inside and outside the border of the MPAs, exploiting the discontinuity associated with the border of the protected areas[1]. Considering the richness and characteristics of the data used, in addition to exploiting these discontinuities given by the borders of the protected areas, I also examine the heterogeneities generated by the type of protection designation.

I find that protected areas with stricter protection designations significantly reduce fishing efforts. The results suggest that although all the protected areas analyzed have the same potential and incentive to be exploited[2], those protected areas with defined designation of partial or total restriction of their area as "*no-take*"[3], have a significant local effect in reducing the fishing effort within them. This suggests a dissuasive effect that may be associated with a greater capacity to enforce regulations in these MPAs, given the greater conservation interest that is associated with these areas. On average, these types of protected areas have reduced fishing efforts by 94,796 hours, a reduction that represents 30.5% of the fishing efforts per km^2 worldwide between 2016 - 2020. Second, I find a local effect on the border that suggests evidence of vessels' use of the positive *spillover* in fish abundance generated by the MPAs. This behavior may be associated with lower levels of enforcement[4] that do not dissuade vessels, considering, in addition, the exploitation incentives that boats have on protected ecosystems, given their greater wealth and environmental diversity.

[1]For some works where the same methodology has been used for similar analyses, see Englander (2019) and Bonilla-Mejía and Higuera-Mendieta (2019)

[2]Using information on the concentration of phytoplankton as a measure of productivity, it is found that the MPAs have better indicators of productivity in their interior compared to observations outside the limits of the MPA.

[3]The *no-take* zones are areas to the within MPAs established by governments where any type of activity is totally prohibited. Some MPAs have this type of designation in their entire coverage while others only in defined sub-areas within the MPA.

[4]The designation of fewer restrictions is associated with less commitment by protected area managers to strengthen enforcement of regulations (Albers et al., 2020).

This paper contributes to the literature on the effectiveness of MPAs in several ways. First of all, this is, to the best of my knowledge, the first study that assess the causal effects of MPAs on industrial fishing activity with global coverage of MPAs, using high-resolution data of fishing efforts and non-parametric spatial discontinuity regression models (RD). Previous works have studied the effects of MPAs on ecological variables and artisanal fishing activity, considering cross-sectional estimates based —in the best of cases, to capture causal effects— on matching methods that control only for observed variables (Ahmadia et al., 2015, Gill et al., 2017, Harasti et al., 2019, Davis and Harasti, 2020). Meanwhile, the RD approach proposed here also considers unobserved characteristics that, when not considered, potentially generate bias in the estimates[5]

Second, new global evidence is provided at pixel-level resolution of the relationship between industrial fishing and maritime environmental conservation instruments. As far as is known, there are no globally representative studies that lead to general conclusions on the relationship between protected areas and industrial fishing.

The rest of the article is organized as follows. Section 2 presents the conceptual framework, discussing the legal and institutional background of the MPAs and fishing restrictions. Section 3 discusses the related literature. Section 4 describes the data and the implemented methodology. Finally, the results are presented in Section 5, and the conclusions in Section 6.

2 Marine Protected Areas and fishing control

The use of Marine Protected Areas as instruments of environmental conservation policy dates back to 1935 with the designation of the Fort Jefferson National Monument in Florida,

[5]Other identification strategies such as differences in differences could be used. However, there is evidence in the literature of an anticipation effect (McDermott et al., 2019, Colmer et al., sf), which violates the assumption of parallel trends.

United States, covering approximately 18,850 hectares (ha) of sea. However, it was not until 1962, during the first Congress on National Parks, that the conservation objectives and interests of international organizations began to be established. By 1970, there were already 118 MPAs from 27 countries around the world (Humphreys and Clark, 2020).

The first thing required for the creation of an MPA is a proposal by national governments, non-governmental organizations, and communities, among other entities. These bodies will be in charge of managing each of the requirements for the design and implementation of protected areas.

These protected areas are designated to be developed within the limits of the exclusive economic zones of each country[6]. Therefore, when a new protected area is created, the entity promoting its creation will be responsible for its management, monitoring, and control. There are other types of MPAs implemented in international waters, known as Marine Areas beyond national jurisdiction and these are managed by more than one national government or by international organizations[7].

The implementation of marine areas often involves a *trade-off* between conservation and the social well-being of communities dependent on marine resources, which will necessarily lead to minimal coverage of marine protected areas (Davies et al., 2018). Despite this, all the efforts to conserve the oceans have strengthened the global institutional frameworks for conservation, and improved the structure and definition of the standards for designation, implementation, monitoring, and control of protected areas, in order to contribute, through clearly-defined regulations, to the effectiveness of the MPAs.

Considering that the purpose of the protected areas has been to preserve the nature of the protected ecosystems in the best conditions, restrictions have been set on any type of activity that puts the achievement of this objective at risk. As of 2016, it was agreed that

[6]Approximately 200 nautical miles from the coast to the open sea. This aquatic territory is the exclusive administration/exploitation of each country.

[7]In this work, I will focus exclusively on those areas of national jurisdiction.

no type of extractive activity is compatible with the definition of Marine Protected Areas. Only small-scale non-extractive activities related to research, traditional use, and recreation are accepted. Activities such as mining, oil and gas extraction, untreated waste discharge, habitation, and industrial fishing or aquaculture activities are not permitted within the limits of protected areas. According to the International Union for the Conservation of Nature (IUCN), a protected area that allows these types of activities to take place cannot be understood as an MPA (Day et al., 2019). Failure to comply with these regulations is associated with fines and economic sanctions, up to the suspension of fishing operation licenses (Moutopoulos et al., 2016), which can entail a high cost for the vessels, as a means to persuade them not to breach the regulations.

The reason behind the prohibition of industrial fishing is its negative impact on marine ecosystems, considering that the capture capacity of these vessels is considerably greater, and thus decreases fish stocks and destabilizes their ecosystems (Gibbens, 2018). For these reasons, the institutions around the MPAs have clearly regulated that this type of fishing should be prohibited in the MPAs. Despite the legal framework designed and the increase in the designation of protected areas throughout the oceans around the world, the elimination of industrial fishing activity within these areas is not yet a fulfilled objective (Davis and Harasti, 2020). The potential commercial value that comes from the exploitation of protected areas and the difficulties associated with monitoring these areas have encouraged non-compliance with the regulations (Read et al., 2019).

Mainly, the preservation interest of the MPAs is geared towards ecosystems with greater ecological; environmental; cultural; and, essentially, economic wealth (Day et al., 2019). This greater ecological wealth contributes to the creation of incentives for fishing exploitation by the commercial industry of this sector, for which the interest of preserving protected areas is in conflict with that of exploitation by fishing vessels (Davies et al., 2018). Thus, the greater the ecological richness of the protected areas, the greater the expected exploitation interests, and to that extent, the greater the monitoring and controlling efforts of these areas required to guarantee the preservation of the ecosystem.

Unfortunately, the adoption of new monitoring and control technologies has been less dynamic than the implementation of new MPAs, which is explained by the cost associated with the adoption of these new technologies (Rowlands et al., 2019). Patrol vessels navigate these areas to ensure that the fishing regulations for the protected areas are adhered to (Rowlands et al., 2019). Another factor that has an impact within this scheme is the demarcation of the borders of the MPAs (Gill et al., 2017).). These borders are mapped by geographic information systems, and are not visible, mainly due to the cost of demarcating the areas (Ruopoli, 2006). However, vessels are aware of the existence and placement of these borders through the use of geographic location systems (Englander, 2019), and so could not plead ignorance in carrying out any unregulated fishing activity. In this order of ideas, the probability that a vessel will be detected is determined by the leading institution's level of capacity to enforce the regulations, considering the monitoring, control, and demarcation of borders (Keane et al., 2008, Kelaher et al., 2015). For example, consider a vessel fishing around a protected area. This will have all the incentive to fish inside the MPA to the extent that it does not detect vessels patrolling nearby. However, considering the cost of being detected, i.e., a suspension of the operating license, the vessel will potentially fish only up to the point where it is able to flee from inside the protected area in case it is in danger of being caught (think of the economics of crime literature (Becker, 1968)).

In general, an important implication of strengthening maritime environmental conservation instruments such as MPAs is the greater dissuasion of industrial fishing, and the consequent reduction of pressure on ecosystems. This, in turn, results in the improvement of habitat quality; the increase in the stock of fish; and long-term benefits such as sustainability, not only of the maritime ecosystem but also of the economy of regions that are dependent on ecosystem resources (Hilborn et al., 2020, Marcos et al., 2021).

3 Empirical framework

3.1 Data

Fishing efforts

I use georeferenced information on industrial fishing activity measured by the number of hours of activity from 2016 to 2020. This information is provided by Global Fishing Watch (GFW), and reported in grids of 0.1 degrees; that is, grids of approximately 11Km x 11Km resolution globally. Fishing efforts are reported in a daily time window, which is built based on information from automatic identification systems (AIS), vessel monitoring systems (VMS), and satellite images, which are processed using machine learning, allowing the observation and prediction of vessels that are fishing according to the type of trajectory[8].

GFW detects industrial vessels and predicts the number of hours of their fishing activity in a given pixel. About 2.9 million vessels can be monitored through AIS and VMS systems. However, these systems are susceptible to spoofing and location manipulation, and do not consider the universe of vessels. Through the use of satellite images and automatic learning algorithms, the vessels' monitoring capacity can be improved and problems of spoofing and location manipulation found in other monitoring systems solved.

The information used emphasizes the observation of industrial fishing activity, leaving aside traditional fishing activity[9]; which is relevant given that one third of global fishing is carried out by industrial-level vessels (FAO, 2020). On the other hand, the data reported by the GFW have a greater capacity for fishing activity observation. This is associated, not only with the activity as such, but also with improvements in observation technologies,

[8] A variety of studies have found it appropriate to use this data for the analysis of fishing in different contexts (Englander, 2019, Kroodsma et al., 2018), for more information GFW has a repository of research, which uses this data, see https://globalfishingwatch.org/publications/

[9] AIS and VMS information sources are given for industrial type vessels, likewise, detection by satellite images is given in resolutions that prevent the capture of small boats, characteristics of artisanal fishing.

for which the date range is selected where the average of the fishing effort is constant over the years.

The number of total hours of fishing activity, according to the objectives of this research, will be understood as a measure of industrial vessels' fishing efforts in the ocean. The number of hours per pixel from 2016 to 2020 are added, in order to be able to identify the amount of fishing effort that has taken place in the Marine Protected Areas during the study period. For the years analyzed, on average, the hours of fishing within the MPAs add up to 32.6 hours while outside of them, they total 73.9. The latter is applied to a buffer of 88 km around the border, which varies by region and level of restriction (Table 1).

[Table 1 about here.]

Marine Protected Areas

Protected areas are identified using data from the World Database Protected Areas (WDPA), which is managed by the World Conservation Monitoring Center (UNEP-WCMC) and by the International Union for Conservation of Nature (IUCN) (UNEP-WCMC and IUCN, 2023). This database contains information about the characteristics of Marine Protected Areas around the world. I use a final database, as of 2020, in which there are approximately 434 MPAs with an average age of 28 years, of which 47 have regulations that prohibit any type of activity (*no-take*), 60 have partial protection, while 49 register that they do not have any type of strict restriction. The rest are not registered. Table 2 highlights that in the last 10 years MPAs have increased both in number and in coverage, which is explained by the greater interest in conserving marine ecosystems.

Given the representativeness and objective of this study, I use protected areas of national jurisdiction. These include those protected areas whose administration depends on certain countries, to the extent that, in the world, approximately 25 million km^2 of the oceans are protected by MPAs under national jurisdiction, while less than 5 million km^2 are attributed to areas beyond national jurisdiction. I also consider only those fully marine areas, which do not contain land surface within their limits, and I restrict the sample to those MPAs created before 2016. Figure 1 illustrates the coverage and extension of the 434 marine protected areas studied.

[Table 2 about here.]

Finally, considering the richness and characteristics of the data used, in addition to exploiting the discontinuities associated with the borders of protected areas to measure their effectiveness in controlling industrial fishing activity, I also assess the heterogeneities generated by the designated type of protection and the role of certain conservation strategies in explaining the dynamics in the relationship between fishing efforts and marine protected areas.

[Figure 1 about here.]

3.2 Identification Strategy

A growing body of research has studied the effects of marine protection areas on conservation objectives. However, within the framework of analysis of this relationship, empirical difficulties arise related to the assignment of MPAs, which are not randomly assigned, but whose designation is determined by a series of observable variables. This means that comparisons between points located outside and inside the MPAs lead to biased estimates. Some works have attempted to deal with this identification problem using matching methods designed to strike a balance in the sample through the observed variables of the characteristics of ecosystems, oceans, and MPAs (Ahmadia et al., 2015, Gill et al., 2017). Although this method solves the problems conditional on the observable variables, it leaves out unobservable characteristics that are also determining factors and that can lead to bias in the estimates[10]. Other works have been conducted using other methodologies; however, these fail to capture causal effects (Harasti et al., 2019, Davis and Harasti, 2020).

To deal with the endogeneity problem, the sample could be restricted to the closest observations to the MPA borders (around a buffer of 88km). To this end, the observations that are within an MPA will be taken as the treatment group, while the control group will consist of those cells just outside the MPA but inside the buffer (Figure 2). Each cell counts information on industrial fishing activity in the high seas, measured by the number of hours of fishing activity. The following spatial regression discontinuity is estimated, based on this information, to capture the causal effect of MPAs on fishing efforts:

$$Y_{ji} = \alpha + \tau_{RD_0} D_{ji} + \sum_{k=1}^{k} \beta_k X_{ji}^k + D_{ji} \sum_{k=1}^{k} \gamma_k X_{ji}^k + \Gamma_{ji} + \theta_j + \mu_{ji} \tag{1}$$

Where Y_{ji} denotes the fishing effort, measured by the number of hours of activity, at a given pixel, denoted by i, at MPA j. D_{ji} is an indicative variable that takes the value of 1 if the observation is inside the MPA or 0 if it is outside. The variable X_{ji} indicates the minimum distance to the MPA border by the cells. Controls such as depth, distance to the coast and phytoplankton concentration Γ_{ji} are included, and it is also controlled by a polynomial of order k of the distance to the MPA border. Finally, fixed effects per MPA and region θ_j are added.

[Figure 2 about here.]

The effect is estimated using the model proposed by Calonico et al. (2014), which selects the optimal bandwidth and computes the conditional mean difference between cells inside (treatment) and outside (control) protected areas. However, given the existence

[10]Additionally, for the analysis carried out here, there is not enough availability of variables with high resolution that are decisive in explaining why an area is designated as an MPA, which is necessary to be able to consider the application of matching methods such as Propensity Score Matching (PSM).

of *spillovers*, which can influence the estimation of the optimal bandwidth, I contrast the results with an arbitrary assigned bandwidth of 80kms, a distance that on average represents 16.8% of the total area of MPAs.

The parameter of interest is τ_{RD_0}which captures the average effect on global fishing efforts over the study period. This effect is calculated in units of the number of hours of fishing activities; that is, it expresses the number of hours in which fishing has not taken place in a pixel i as it is within an MPA. The main assumption to hold is that the baseline features are normally distributed across the boundary. To verify the fulfillment of this assumption, I use the continuous distribution test of the covariates proposed by Canay and Kamat (2018), which I present in Table 3[11]. As a result, the variables of depth, phytoplankton concentration index, and distance to the coast are continuously distributed along the border of the MPAs, except for those that do not report designation. Therefore, when validating the assumption of continuity, it can be assumed that both observable and unobservable characteristics can be controlled, and the estimates presented can be interpreted as causal.

4 Results

TThe results are organized in three parts. First, I estimate the total average effect of marine protected areas on industrial fishing efforts with the total sample that meets the assumption of continuity (Table 3), finding evidence that although MPAs reduce fishing efforts within, there is a concentration of fishing activity on their very borders. To validate these results, I then estimate the effect for each of the restriction levels (total, partial, unrestricted, and unreported), finding that those areas with a clear definition and with greater restrictions present better results in controlling fishing activity, while more fishing

[11]The null hypothesis of the permutation test of Canay and Kamat (2018) is that there exists continuity of covariates in baseline at the frontier. I test the covariates individually with 1,000 permutations.

takes place in those with less restriction or greater lack of clarity in their designation.

[Table 3 about here.]

4.1 Average effect of marine protected areas

Table 4 illustrates the effect of MPAs on fishing efforts. I find that MPAs at optimal bandwidth calculated following Calonico et al. (2014) do not have a statistically significant effect on fishing efforts; however, when I remove the observations around 10km from the border, as a correction measure for *spillover* (Donut hole approach)[12], , I find a significant effect of approximately 10.8 hours, which represents a reduction of 78,094 hours (7.31%) of fishing hours per km^2 that took place globally, in the study period.

[Figure 3 about here.]

Figure 3 illustrates how the concentration of fishing around the border affects the estimation of the optimal bandwidth. As such, to support the previous results, I estimate the effect of the MPAs for an arbitrary bandwidth of 88kms, finding that protected areas potentially reduce fishing efforts by between 7.69 and 14.9 average hours per pixel. This is equal to approximately 6.65% and 10.1% of the fishing hours per km^2 that are performed in the world, respectively. These reductions in fishing help to increase higher quality ecosystems.

Table A3 presents the results of an OLS estimate of the relationship between fishing activity and phytoplankton concentration. The results indicate that the greater fishing activity around the borders of the MPAs may be negatively influencing the quality of the phytoplankton concentration in these protected areas[13]. Phytoplankton concentration is a

[12] There is evidence in the literature that MPAs generate a spillover in fish production (Cuervo-Sánchez et al., 2018), which is known to the vessels and which they take advantage of when carrying out fishing activity.

[13] It may also be explained by the incidence of the presence of boats, which contribute to the deterioration of the quality of the phytoplanktons due to the movements of the rotors (Das Sarkar et al., 2019)

key factor in biological terms of the quality of the ecosystems (Lewis et al., 2020). Thus, given the results presented of the effectiveness of MPA control of fishing, the reduced fishing activity would, therefore, contribute to better ecological indicators in these areas.

Figure 3 also shows that fishing efforts within some MPAs take place only up to a certain distance. My hypothesis in terms of this empirical fact is that those vessels that decide to fish illegally within the MPAs, decide to do so only to the point where they are able to leave the protected areas in the event that they are at risk of being detected. Despite the above, this hypothesis was not empirically evaluated in the present work, so it remains for future research to evaluate the empirical validity of this hypothesis of the strategic behavior of the vessels that fish illegally in MPAs.

[Table 4 about here.]

Even when we can observe that the assumption of continuity of the covariates in the baseline is fulfilled, when validating the continuity of variables such as depth and phytoplankton concentration (Table 3), deep inside the MPAs, the phytoplankton concentration appears to be higher (Figure A1). This plays a significant role in explaining vessels' incentives to fish inside protected areas, given their greater productivity[14]. In this line, we can associate that the reduction of fishing efforts that I find is given by the managing entities' capacity to enforce regulations in these areas (Gill et al., 2017). As a robustness check, I estimate the effect of MPAs for areas created at the end of 2020 and find no statistically significant effect. Figure A2 presents the graphic form of this effect, suggesting that the reduction in fishing efforts is essentially due to the presence of marine protected areas.

These results are consistent with the results observed in the literature that indicate that the MPAs have improved the quality indicators of protected ecosystems (Edgar et al., 2014,

[14]The concentration of phytoplankton in the literature has been used as a good approximation of the productivity of marine ecosystems (Lewis et al., 2020)

Gill et al., 2017). We can assert that this has been given by the effect of MPAs in reducing industrial fishing efforts inside, decreasing catch rates and increasing fish production, through the ecosystems' best restoration capacity (Hilborn et al., 2020).

4.2 Restriction levels and conservation objectives

Table 5 presents the results of the estimations by level of restriction. I find that those areas with a greater restriction present better results in the control of fishing and therefore in the conservation objectives. The MPAs with a total restriction generate reductions in fishing efforts that represent 11.3% of the total fishing efforts per km^2 that took place globally between 2016 - 2020. On the other hand, the protected areas with partial restriction, the most representative within the sample, generate reductions of 40.5%. Adding these effects, we would be obtaining that, on average, the MPAs have generated reductions that represent 30.5% of the total fishing per km^2. These results are in line with the related literature on the ecological effectiveness of "*no-take*" MPAs (Campbell et al., 2012, Bergseth et al., 2013, Miller and Russ, 2014, Advani et al., 2015, Sala and Giakoumi, 2018, Harasti et al., 2019, Davis and Harasti, 2020) .

In contrast, I find no significance for those areas designated with no restrictions, while the highest incidence of fishing within a protected area takes place in those areas that do not report any type of restriction. However, it is not clear that it is this lack of restriction that is generating this phenomenon. Nevertheless, it does seem to be clear that a lack of clarity in their designation creates incentives for non-compliance with fishing restrictions.

[Figure 4 about here.]

Table A2 contrasts the results of the estimations between the optimal bandwidth and the one arbitrarily assigned in 80kms. No evidence of significant results is found at the optimal bandwidths, which is explained by the existence of *spillovers*. Table A4 presents the results by IUCN category and restriction level of "*no-take*"[15]. The results are varied. No robustness is found between the definition of the categories and the level of restriction; thus, the IUCN categories are not considered for the main estimates.

[Table 5 about here.]

As robustness checks, the coefficients are estimated at different bandwidths and *spillover* widths. These results are presented in Figures A3 and A4, respectively. There is evidence of some fragility in the results at different bandwidths, which I believe can be explained by the difficulty in correctly designating the limits of the borders (Ruopoli, 2006) and the incidence of *spillover* (Cuervo-Sánchez et al., 2018).

5 Conclusions

This article examines the effects of Marine Protected Areas (MPAs) on fishing efforts globally using high-resolution data from industrial fishing activity. The use of the non-parametric spatial RD method as a solution mechanism to the selection problems associated with the non-random assignment of MPAs is addressed. The results presented here are useful for the design and control of environmental conservation policies.

I find that, on average, the MPAs have reduced industrial fishing efforts by 94,796 hours, a reduction that represents 30.5% of the total hours of fishing per km^2 that took place worldwide from 2016 - 2020. However, I find a local effect on the border of some areas that suggests evidence of a negative use by the vessels of the *spillover* generated by the MPAs. I evaluate that this behavior may be associated with the lack of clarity in the designation of protected areas, which does not help to dissuade vessels, considering, also,

[15]Given the availability of information, the regressions are only estimated for those combinations of categories and level of restriction restriction with enough data.

the vessels' incentives for exploitation in protected ecosystems, given their greater wealth and environmental diversity.

I find that protected areas with a stricter protection designation significantly reduce industrial fishing efforts. In this sense, I find that, on average, all MPAs have better productivity indicators within them, that is, they all have the same potential and incentive to be exploited. However, those protected areas with a defined designation of partial or total restriction have a significant local effect on reducing fishing efforts within them, suggesting a dissuasive effect that may be associated with the greater ability to enforce regulations in these MPAs.

In general, Marine Protected Areas are effective in controlling industrial fishing activity, thus contributing to the fulfillment of their conservation objectives. Hence, the strengthening of environmental conservation instruments is imperative for the preservation of ecosystems and the environmental and economic wealth that results from them. However, the case of maritime ecosystems also requires an understanding of the behavior of fishing activity around these conservation instruments, so that it can contribute to improving the effectiveness of protected areas, and as a result, improving ecological indicators.

Conservation efforts must be reinforced and be made homogeneous through all MPAs in the world. All designated protected areas should have the same level of importance given the conservation objectives, so as to increase the clarity and enforcement of the regulations around these environmental policy instruments.

There is much literature on understanding the impact that protected areas have on maritime ecosystems. However, literature on the role of MPAs in the fishing activity itself, and especially industrial activity —which has the greatest capacity to affect ecosystems— is rather scarce. This study that evaluates the behavior of this type of fishing within the framework of protected areas contributes to better explaining how marine protected areas should be designed, implemented, monitored, and controlled.

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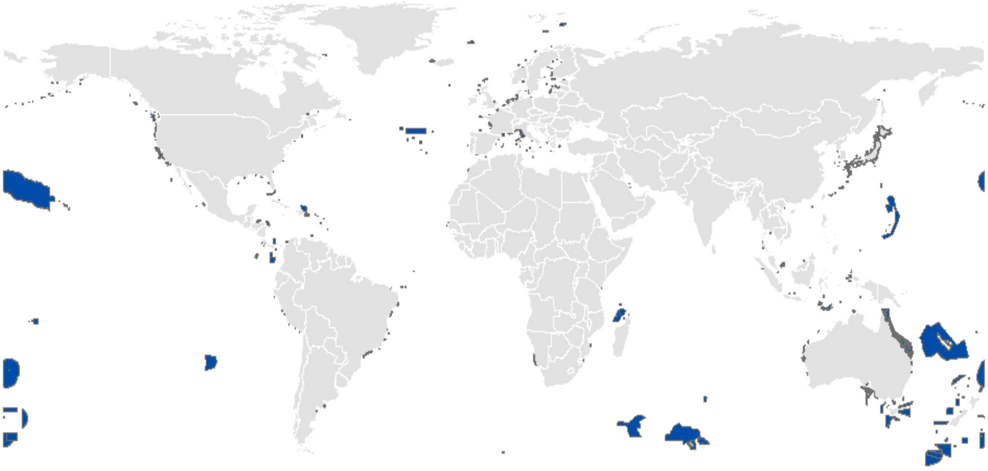


Figure 1: Map of Marine Protected Areas as of 2020. Author, using information from WDPA. Note: The figure shows the analyzed marine protection areas in blue.

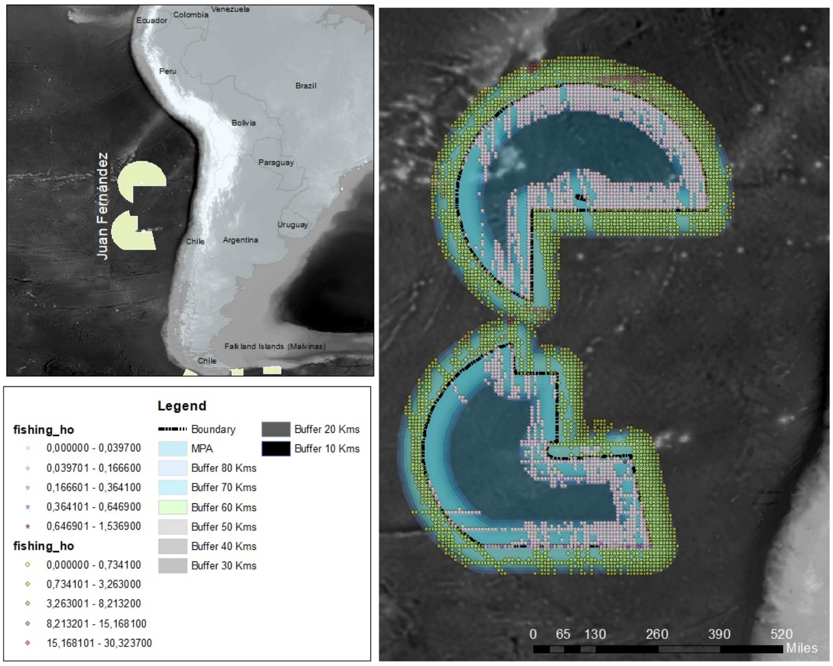
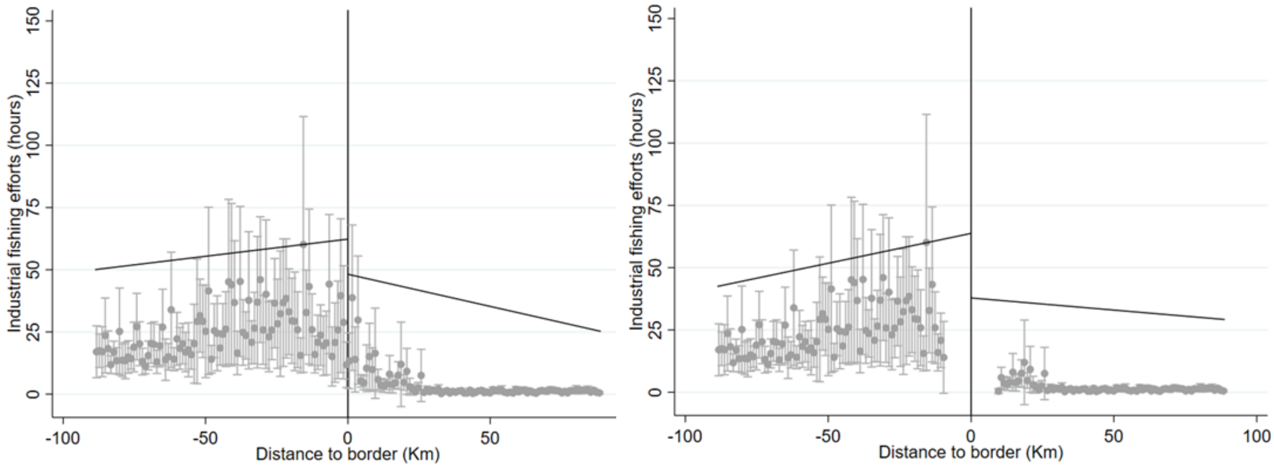


Figure 2: Treatment and control assignment. Source: Author, using information from GFW and WDPA . Note: The figure illustrates the protected area of the Juan Fern´andez Sea in Chile. The black dotted lines indicate the border of the protected area, their thickness indicates different buffer widths. All observations in points reflect the fishing activity detected. The yellow scale points are the control observations (outside the MPA) and the purple scale points are the treated observations (within the MPA).



(a) (b)

Figure 3: Effect of MPAs on fishing activity. Source: Author, using information from GFW and WDPA . Note: Observations are clustered at 1-km intervals and smoothed with a covariate-adjusted linear polynomial. The observations to the left of the cut-off point are those that are outside the protected area, while those to the right are those that are inside. The bars represent the confidence intervals at the 95% confidence level. Panel (a) contains all the observations, and panel (b) removes the observations within 10 km of the boundary.

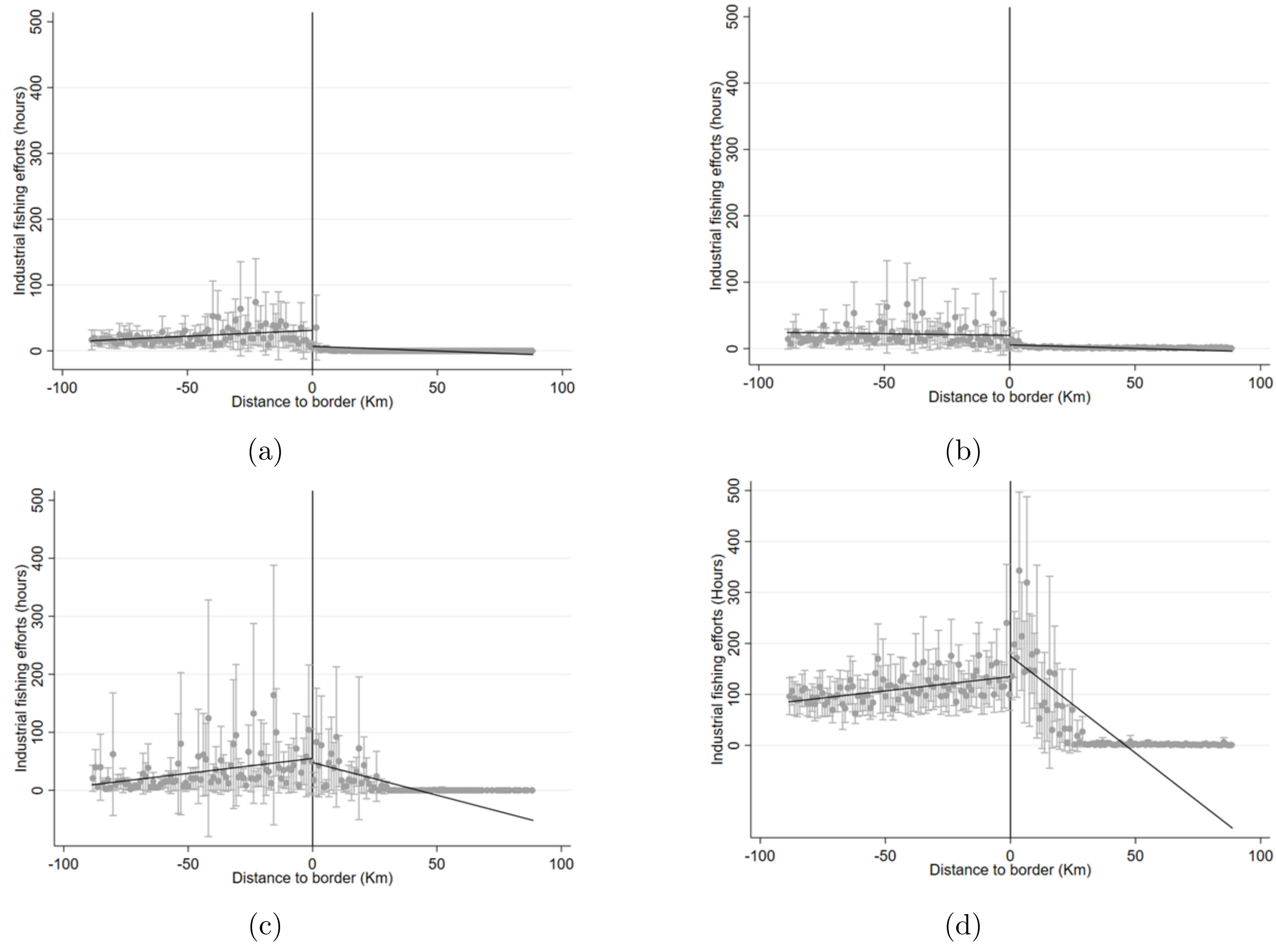


Figure 4: Effects of MPAs on fishing effort by level of protection. Note: : Observations are clustered at 1-km intervals and smoothed with a covariate-adjusted linear polynomial. The observations to the left of the cut-off point are those that are outside the protected area, while those to the right are those that are inside. The bars represent the confidence intervals at the 95% confidence level. Panel (a) Total protection, (b) Partial protection, (c) No protection and (d) Protection not reported.

Table 1: Industrial fishing activity 2016 - 2020

	Treatment				**Control**				**Difference**
	Mean	**Standard Deviation**	**Min.**	**Max.**	**Mean**	**Standard Deviation**	**Min.**	**Max.**	**P-value**
A. Regions									
East Asia and the Pacific	16.14	224.89	0	13940.5	65.20	457.88	0	17385.2	0.000
Europe and Central Asia	230.85	804.16	0	10970.7	172.32	502.67	0	8224.9	0.000
Latin America and the Caribbean	3.70	17.04	0	200.48	24.81	137.94	0	6382.9	0.000
Middle East and North Africa	295.96	566.56	0	1445.2	142.67	504.13	0	5844.8	0.461
North America	12.48	103.16	0	3068.9	34.18	157.81	0	3743.2	0.000
Sub-Saharan Africa	9.26	24.26	0	109.85	80.39	382.31	0	6074.9	0.128
B. Protection Designation "No Take"									
Total	3.44	52.09	0	1510.9	22.38	117.6	0	3743.2	0.000
Partial	2.31	31.52	0	2336.6	20.63	141.5	0	4633.6	0.000
None	24.69	148.6	0	3068.9	31.55	202.1	0	6074.9	0.272
Not Reported	82.12	494.9	0	13940.5	108.9	481.7	0	17385.2	0.000

Source: Author's calculations based on WDPA and GFW data. Note: Fishing activity is measured as the sum of the number of hours from 2016 - 2020. The last column presents the p-value of the mean difference between treatment and control.

Table 2: Area of marine protected areas 2010 - 2020

	2010		2020	
	No.	*Coverage (km^2)*	*No.*	*Coverage (km^2)*
A. Regions				
East Asia and the Pacific	99	1.432.023	153	3.021.285
Europe and Central Asia	81	76.043	115	215.248
Latin America and the Caribbean	42	279.514	47	331.012
Middle East and North Africa	4	560	5	1124
North America	57	1.949.358	70	1.953.872
Sub-Saharan Africa	9	16.718	9	16.718
B. Protection Designation "*No Take*"				
Total	31	725.479	47	725.118
Partial	54	1.317.552	60	1.377.580
None	34	312.250	42	347.782
Not Reported	187	1.497.332	264	1.815.278
Total	316	5.356.191	434	7.213.431

Source: WDPA. Author's calculations. Note: The total number and the sum of the total coverage of the sample of marine protected areas registered by the WDPA as of 2010 and 2020 are presented.

Table 3: Continuous distribution of baseline ocean characteristics at MPAs borders by "*no-take*" restriction level

	Treatment		Control		Permutation test	
	Mean	**Standard Deviation**	**Media**	**Standard Deviation**	**t-Test**	**p-value**
A. Total						
Depth (m)	-2789	1913	-1223	1641	0.01	0.8
Phytoplankton Concentration Index	144.03	37.24	136.4	47.65	0.05	0.22
Distance to the coast (km)	367	300.8	155.9	250.7	0.02	0.57
B. Partial						
Depth (m)	-3443	1629	-3110	1861	0.27	0.00***
Phytoplankton Concentration Index	124.6	54.6	124.9	52.44	0.05	0.18
Distance to the coast (km)	483.8	417.8	442.6	401.6	0.03	0.34
C. None						
Depth (m)	-3484	2736	-2114	2229	0.09	0.06
Phytoplankton Concentration Index	123.3	60.46	141.8	52.91	0.06	0.12
Distance to the coast (km)	284.6	254	140.8	170.9	0.13	0.02**
D. Not Reported						
Depth (m)	-2316	2127	-1360	1507	0.16	0.00***
Phytoplankton Concentration Index	124.1	48.86	132.6	51.93	0.14	0.01**
Distance to the coast (km)	277.1	266.7	144.4	206.6	0.34	0.00***

Source: Author, using NOAA database. Note: * p<.10, * p<.05, ** p<.01. The first two columns present the descriptive statistics of the observations within the 88 km buffer around the border of the MPAs. The last two columns show the results of the continuous distribution test of the covariates proposed by Canay and Kamat (2018) with 1,000 permutations. The null hypothesis is that there is continuity of the baseline covariates at the cutoff point.

Table 4: Regression discontinuity: Effects of MPAs on industrial fishing effort

	All Obs.		**Donut Hole**	
	Optimal	**80kms**	**Optimal**	**80kms**
	(1)	**(2)**	**(3)**	**(4)**
MPAs	0.26	-7.69**	-10.8**	-14.9***
	(5.73)	(3.19)	(4.30)	(3.42)
Mean (Yi)	27.2	23.8	26.8	23.9
Bandwidth	26.05	80	61.09	80
% of mean	0.9	32.3	40.3	62.3
Observations	39673	39673	35263	35263

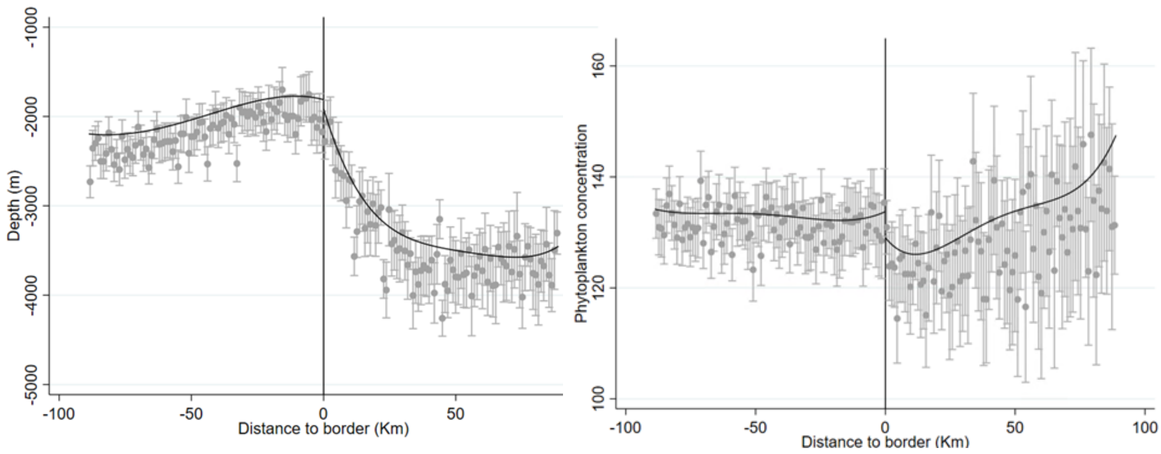
Source: Author, using databases from GFW and WDPA. Note: * p<.10, * p<.05, ** p<.01. The dependent variable is the fishing activity which is represented in hours. Each column indicates the results of an RD estimate from Calonico et al. (2014) with robustness bias correction. Column (1) presents the results of the regression with the complete sample with optimal bandwidth. Obs treated 9240, (2) present the regression results with the full sample with assigned bandwidth. Obs treated 9240, (3) presents the results without 10Kms around the border with optimal bandwidth. Obs treated 7231, and (4) presents the results without 10Kms around the border with allocated bandwidth. Obs treated 7231. Controls and fixed effects by MPA and region are included. Standard errors in parentheses based on the nearest neighbor variance estimator.

Table 5: Regression discontinuity: Effects of MPAs on fishing effort by restriction level

	Total Restriction (1)	**Partial Restriction (2)**	**No Restriction (3)**	**Not Reported (4)**
MPAs	-13.22***	-10.46***	11.98	85.42***
	(5.05)	(3.20)	(23.28)	(19.9)
Mean (Yi)	23.1	21.33	31.56	110.6
Bandwidth	80	80	80	80
% of mean	57.2	49	37.9	77.2
Observations	11654	23491	4528	39764

Source: Author, using data from GFW and WDPA. Note: * p<.10, * p<.05, ** p<.01. The dependent variable is the fishing activity which is represented in hours. Each column indicates the results of an RD estimate from Calonico et al. (2014) with robustness bias correction. Column (1) for the sample of fully restricted MPAs. Obs treated 920, (2) for MPAs with partial restriction, obs treated 7900, (3) for MPAs without restriction. Obs treated 420, and (4) for MPAs that do not report restriction. Obs treated 3280. Fixed effects by MPA and region are included. Standard errors in parentheses based on the nearest neighbor variance estimator.

A Appendix



(a) (b)

Figure A1: Depth and productivity in MPAs. Note: Observations are clustered at 1-km intervals and smoothed with a covariate-adjusted linear polynomial. The observations to the left of the cut-off point are those that are outside the protected area, while those to the right are those that are inside. The bars represent the confidence intervals at the 95% confidence level. Panel (a) Depth, and (b) Phytoplankton concentration.

Table A1: Baseline characteristics balance test by "*no-take*" constraint level

	Total		**Partial**		**None**		**Not reported**	
	Depth	**Phytoplankton concentration**	**Depth**	**Phytoplankton concentration**	**Depth**	**Phytoplankton concentration**	**Depth**	**Phytoplankton concentration**
MPAs	-77.39	-3.86	-32.17	-5.53**	-74.03	-0.80	35.08*	-6.20***
	(97.44)	(3.54)	(67.91)	(2.14)	(89.42)	(5.48)	(20.59)	(1.73)
Bandwidth	80	80	80	80	80	80	80	80
Observations	11654	11654	23491	23491	4528	4528	39761	39761

Source: Author, using data from GFW and WDPA. Note: * p<.10, * p<.05, ** p<.01. Fishing activity is represented in hours. Each column indicates the results of an RD estimate from Calonico et al. (2014) with bias correction for robustness, with a polynomial of degree 2. All regressions include MPA and region fixed effects. All controls are included.

Table A2: Regressions at different bandwidths

	Total		**Partial**		**None**		**Not reported**	
	Optimal	**80kms**	**Optimal**	**80kms**	**Optimal**	**80kms**	**Optimal**	**80kms**
MPAs	2.74	-13.22***	-2.36	-10.46***	-28.77	11.98	13.78	85.42***
	(7.75)	(5.05)	(6.22)	(3.20)	(44.01)	(23.28)	(34.88)	(19.9)
Bandwidth	20.01	80	23.42	80	9.46	80	9.79	80
Observations	11654	11654	23491	23491	4528	4528	39761	39761

Source: Author, using data from GFW and WDPA. Note: * p<.10, * p<.05, ** p<.01. Fishing activity is represented in hours. Each column indicates the results of an RD estimate from Calonico et al. (2014) with bias correction for robustness, with a polynomial of degree 1. All regressions include MPA and region fixed effects. All controls are included.

Table A3: OLS estimates: Effect of industrial fishing on phytoplankton concentration

	Dependent variable: Phytoplankton concentration		
	(1)	**(2)**	**(3)**
Fishing activity	-0.0023***	-0.0037***	-0.0039***
	(0.0005)	(0.0005)	(0.0005)
FE region	No	No	Yes
FE MPA	No	Yes	Yes
Controls	Yes	Yes	Yes
Observations	94334	90240	79434
R2	0.6	11.4	13.8

Source: Own calculations using GFW and NOAA data. Note: * p<.10, * p<.05, ** p<.01. Fishing activity is represented as the sum of the number of fishing hours from 2016 -2020. The concentration of phytoplankton is an index, the higher the index, the higher the concentration.

Table A4: Regression discontinuity effects of MPAs on fishing effort by Protection Category and restriction level according to "*no-take*"

	Total (1)	Partial (2)	None (3)	Not reported (4)
			A. Strict Nature Reserve	
MPAs	-24.25***	-	-	-27.68
	(5.00)			(22.65)
Bandwidth	80	-	-	80
Observations	9023	-	-	1177
			B. National Park	
MPAs	-	-	-	43.60
				(56.6)
Bandwidth	-	-	-	80
Observations	-	-	-	4990
			C. Natural monument or feature	
MPAs	-	-	-	-32.46
				(29.98)
Bandwidth	-	-	-	80
Observations	-	-	-	570
			D. Habitat/species management area	
MPAs	-	-12.35	-	211.5***
		(7.94)		(48.89)
Bandwidth	-	80	-	80
Observations	-	5174	-	12712
			E. Protected seascape	
MPAs	-	-0.99	20.83	-165.7***
		(19.16)	(35.95)	(25.98)
Bandwidth	-	80	80	80
Observations	-	1266	1423	6017
			F. Protected areas with sustainable use of natural resources	
MPAs	-	-8.83***	-40.19	16.84
		(2.03)	(25.43)	(15.11)
Bandwidth	-	80	80	80
Observations	-	14128	1574	14295

Source: Author, using data from GFW and WDPA. Note: * p<.10, * p<.05, ** p<.01. Fishing activity is represented in hours. Each column indicates the results of an RD estimate from Calonico et al. (2014) with bias correction for robustness, with a polynomial of degree 1. All regressions include MPA and region fixed effects. All controls are included. The results are presented only for the categories with enough observations to run the estimate.

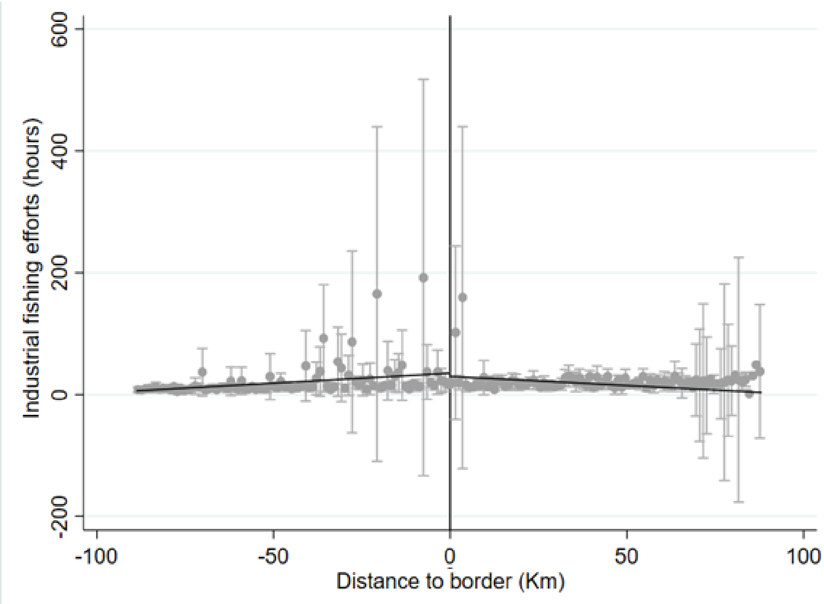
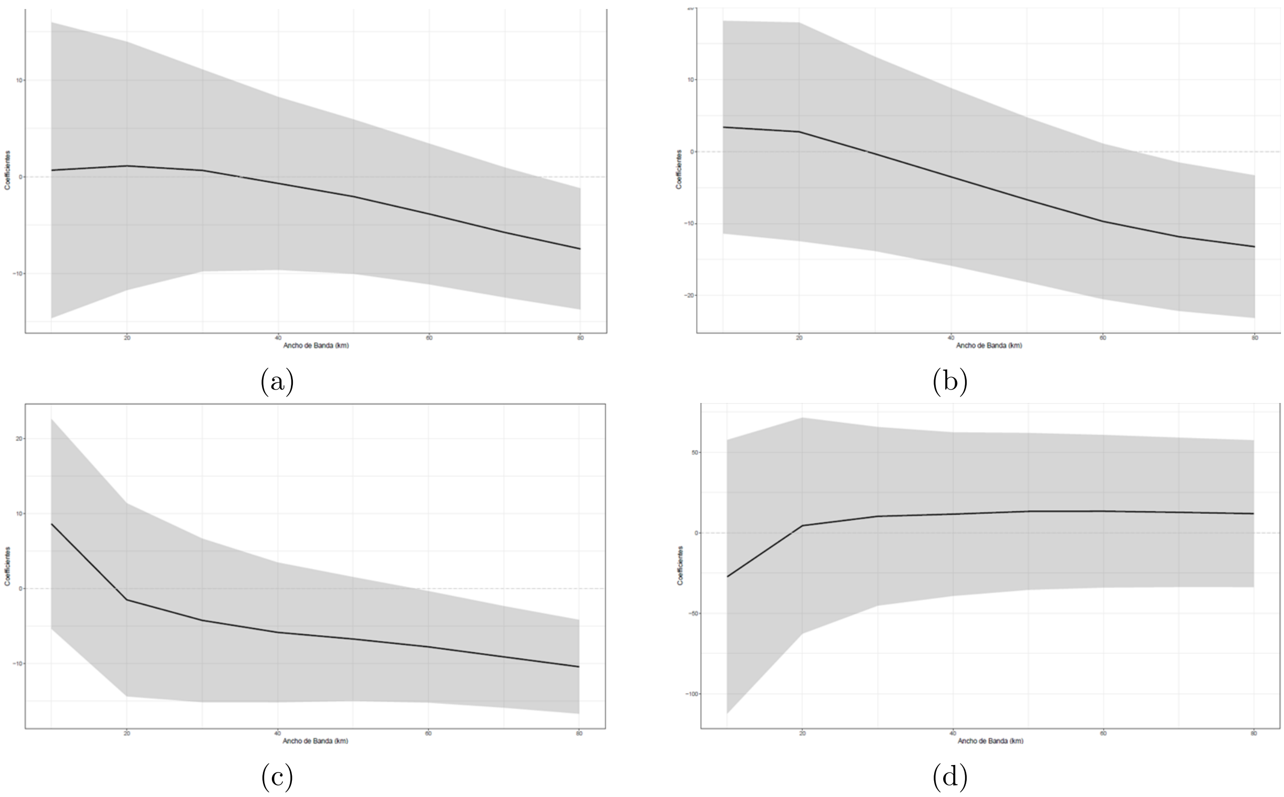


Figure A2: Effects of MPAs on fishing effort for MPAs created in 2020. Note: Placebo test for pre-treatment. Observations are clustered at 1-km intervals and smoothed with a covariate-adjusted linear polynomial. The observations to the left of the cut-off point are those that are outside the protected area, while those to the right are those that are inside. The bars represent the confidence intervals at the 95% confidence level.



(a) (b)

(c) (d)

Figure A3: Bandwidth sensitivity tes. Note: The graph presents the estimate of the treatment effect for different bandwidths at every 10 km up to 80 km. The shaded area represents the confidence intervals at the 95% confidence level. The regressions are done with nearest neighbor corrected standard errors. Panel (a) All, (b) Total protection, (c) Partial protection, and (d) No protection.

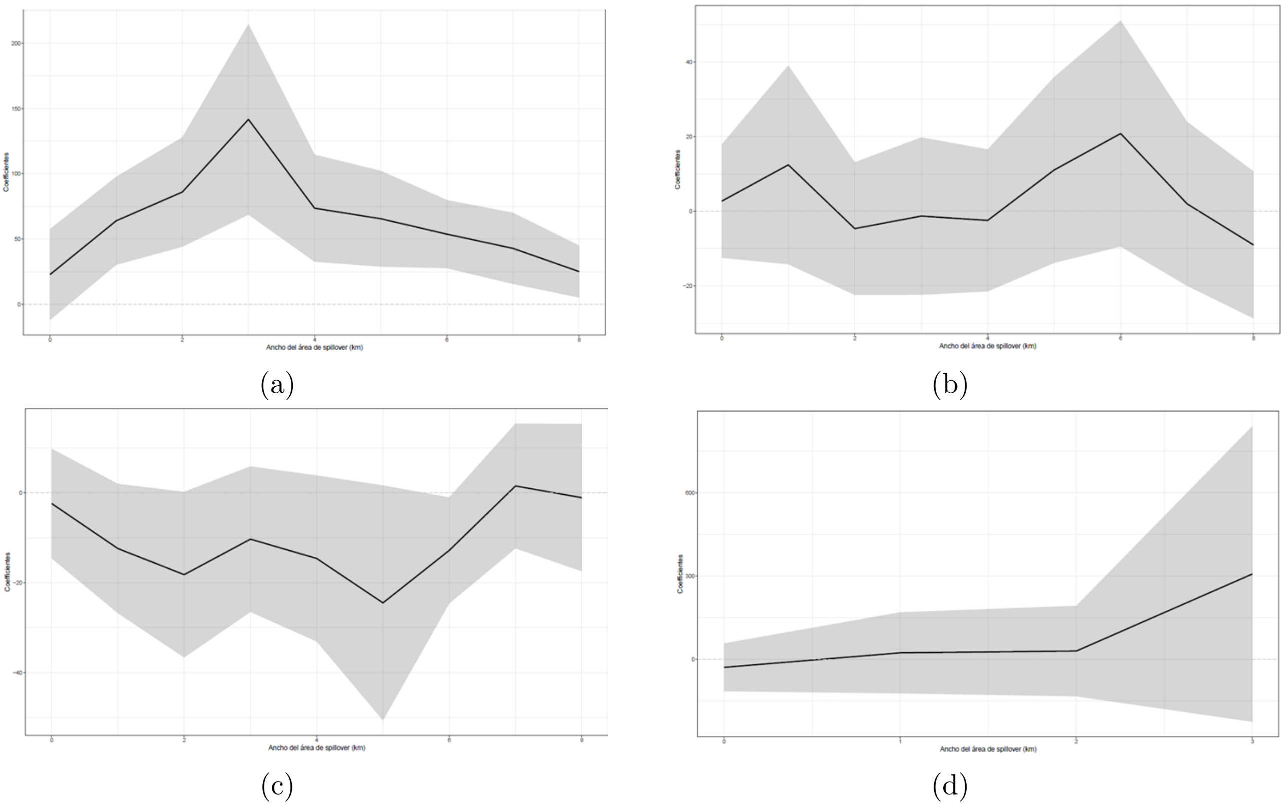


Figure A4: Spillover width sensitivity test. Note: The graph presents the estimator of the treatment effect for different spillover widths, that is, it eliminates observations close to both sides of the border. The regressions are done with nearest neighbor corrected standard errors. The shaded area represents the confidence intervals at the 95% confidence level. Panel (a) All, (b) Total protection, (c) Partial protection, and (d) No protection.