Industrial fishing compliance with a new marine corridor near the Galapagos Islands

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Abstract

Examining fishing pressure in under-resourced marine regions still presents a challenge to understanding patterns of fishing pressure. These issues are compounded in areas with complex marine zoning regulations or those that have changed over time. Satellite-based positioning tracking of fishing vessels has helped identify ocean-wide fishing effort distribution and potential encroachments into marine protected areas (MPAs). However, it is less well known what determines fishing at smaller scales, especially within MPAs where fishing may not be allowed. Here, we use satellite-based fishing vessel positioning to study industrial fishing effort around the Galapagos Marine Reserve, inside the Insular Exclusive Economic Zone of Ecuador (I-EEZ). The region has areas that are open to all fishing, closed to fishing (no-take), open to any fishing except with the use of longline, or (within the Galapagos Marine Reserve) only open to artisanal fishing vessels. From 2019-2023, we identified 145 large, industrial (non-artisanal) fishing vessels (910 gross tonnage on average) from 10 countries fishing within the I-EEZ around the Galapagos. However, 87% of the fishing effort was accounted for by Ecuadorian vessels using tuna purse seines and drifting longlines in equal proportions, while the effort of foreign vessels was accounted for by tuna purse seines. In this time window, we observed 64,626 hours of fishing within the I-EEZ with less than 1% of fishing occurring within the Galapagos Marine Reserve. In addition, we studied the effect of a newly declared MPA in 2022, known as the Hermandad Marine Reserve, which created an additional 60,000 square kilometers of protected area. We documented an 88% decrease in fishing effort within the Hermandad Marine Reserve after its implementation. There appeared to be a small increase in effort leading up to the reserve's implementation, but no shift in fishing effort distribution elsewhere. Collectively, our results highlight the wide range of fishing activities within and around an important marine protected area, especially for migratory marine megafauna. Our findings have important implications for other zoned marine areas given the diversity of fishing activity in different regions within our study area.

Keywords: industrial fishing, Galapagos, marine protected areas, marine reserve, tuna

Introduction

Satellite-based data vessel positioning data has been useful in improving vessel safety and understanding patterns of trade, tourism, and industrial fishing (Souza et al. 2016; Adland and Jia 2016). Data from Automatic Identification Systems (AIS) or Vessel Monitoring Systems (VMS) provides real-time positioning information of vessels across the world (Cerdeiro et al. 2020; Drakopulos et al. 2022; Zhang et al. 2022). Combined with ground-truthed machine learning algorithms, this data can also be used to understand vessel behavior, including the type of fishing being conducted (Kroodsma et al. 2018; Tickler et al. 2018; Guiet et al. 2019; T. D. White et al. 2020; Easton R. White et al. 2022). In turn, satellite-derived estimates of fishing effort have been important for understanding fishing activity across the globe, especially for areas or fleets with limited catch data (Kroodsma et al. 2018; Tickler et al. 2018; Guiet et al. 2019; T. D. White et al. 2020; Easton R. White et al. 2022). Satellite-derived fishing effort data has been used to understand encroachment into marine protected areas, determine predictors of fishing effort (e.g., oil costs), and help nations with limited enforcement capability monitor their national sovereignty (Kroodsma et al. 2018; Tickler et al. 2018; Guiet et al. 2019; T. D. White et al. 2020; E.R. White et al. 2022).

Marine spatial planning can zone marine areas for different activities with varying sets of regulations (Klein et al. 2010). Marine protected areas (MPAs) are regions where some level of protection, at least on paper, is offered to an area (Chuenpagdee et al. 2013; Rife et al. 2013; Gill et al. 2017). There is a large variation in MPA formats, and how they are defined, implemented, and governed, with some completely open to industrial activities and others completely closed to human use (Day et al. 2012). The IUCN defines a protected area as “A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (Day et al. 2012; UNEP-WCMC and IUCN 2016). Most areas fall in the middle of this distribution with a mix of human use allowed within marine protected areas (Lubchenco 1995; Costanza et al. 1997). However, there is often a lack of baseline data to examine how fishing or ecosystems respond to new marine management restrictions (G. J. Edgar et al. 2004).

Our understanding of fishing pressure within and around MPAs is often limited because of a lack of, or limited accessibility to, data on fishing effort (Geromont and Butterworth 2015; Chrysafi and Kuparinen 2015). In other words, if fishing is prohibited within an area, there is unlikely to be any reports of fishing within the area. Thus, satellite-derived estimates of fishing effort have produced especially useful information in the context of examining fishing effort near protected areas (Boerder, Bryndum-Buchholz, and Worm 2017; Coomber et al. 2016; T. D. White et al. 2020) and possible illegal activities within the zones (Rowlands et al. 2019). There have been several studies focused on the encroachment of industrial fishing and distant-water fishing fleets on local MPAs. However, there is far less work on illegal fishing activities within protected areas given that many areas are designated as strict reserves and are completely closed to fishing. Thus, it is difficult to understand how fishing may operate in these areas, especially if fishing is still happening, but is not being reported locally or visible via VMS or AIS information. In addition, despite the scale of resolution of satellite-derived estimates of fishing, it is still rare that we have data before and after the announcement of a new spatial management practice, such as the implementation of a new MPA. Past work has shown, however, that fishing effort can increase with the announcement of a new MPA (McDermott et al. 2019). After MPA

implementation, fishing effort may remain the same or increase, decrease, or be displaced to a different area (Carr et al. 2013; Belhabib et al. 2020; T. D. White et al. 2020; Easton R. White et al. 2022; Drakopulos et al. 2022; Campos et al. 2023).

To address these knowledge gaps on mixed-use marine areas and regions where new protected areas have recently been established, we studied industrial fishing activity within Ecuador's Insular Exclusive Economic Zone (I-EEZ) that includes the Galapagos Archipelago. The Galapagos Islands are also positioned within the larger regional context of the Eastern Tropical Pacific Marine Corridor, a multi-country marine area home to important migratory species and fishing (Graham J. Edgar et al. 2011; E.R. White et al. 2015; Nalesso et al. 2019; Enright, Meneses-Orellana, and Keith 2021). Ecuador's national fishing law and fishing regulation recognize two levels of fishing vessel scale: industrial and artisanal fishing. Industrial fishing is defined as extractive activity carried out by vessels with hydraulic, mechanized fishing that allow the capture of hydrobiological resources as well as the size of vessels allowing for the storage of large quantities of fish (FAO 2014). Artisanal fishing is defined as fishing and harvesting activity that is carried out individually, autonomously, or collectively, by men or women, family groups or communities, coastal, riverside, inland and island waters, predominantly carried out manually, to improve their quality of life and contribute to food security, with or without the use of an artisanal vessel (Cochrane and Garcia 2009; FAO 2014).

The Galapagos Marine Reserve (GMR) is a 138,000 km^2 area that encircles the Galapagos Islands from the archipelago baseline to 40 miles toward the open sea (Fig. 1, (DPNG 2014)). The GMR is a mixed-use MPA that regulates several uses such as artisanal fishing, tourism activities and research using a zoning scheme to ensure the conservation of the habitats and biodiversity (DPNG 2014; 2016). Currently, there are 188 active small-scale vessels (i.e., less than 12.5 meters length) (Galapagos National Park Directorate 2021) that use a combination of fishing techniques to harvest large pelagic fish, coastal and demersal fish, and shellfish for both local consumption and export (Ramirez-González et al. 2022). To protect marine ecosystems and their species, especially migratory megafauna, the Ecuadorian government declared a new MPA in January 2022, the Hermandad Marine Reserve of 60,000 km^2 ("Executive Degree 319" 2022). This new MPA extends from the northeastern area of the GMR to the maritime border with Costa Rica, covering part of an area of ocean where movements of endangered species such as East Pacific leatherback turtles and scalloped hammerhead sharks have been documented (Hearn et al. 2022). The Hermandad Marine Reserve has a core no-take zone covering 30,000 km^2. Two strips totaling a further 30,000 km^2, where longline gear is not permitted, fringe the core zone.

When the GMR was created in 1998, industrial fishing within its boundaries initially increased, due to a combination of limited enforcement capabilities and delays in the approval of the management plan (Bucaram et al. 2018). Given that the management plan for the Hermandad Reserve was not approved until March 2023 (Ministerio de Ambiente, Agua y Transición Ecológica 2023), and therefore no resources were allocated prior to this date to control and enforcement, we hypothesized that a similar situation may have occurred during this first phase of the new reserve.

In this study, we use satellite-derived estimates of fishing effort from Global Fishing Watch to examine patterns of industrial fishing (only large vessels > 100 tonnes) around the GMR. We

examined fishing patterns within the I-EEZ around the Galapagos Archipelago where more vessels are allowed to fish. We use this data to address three questions: 1) how does fishing effort vary in differently-zoned regions?; 2) how does fishing by different gear types vary over time and across spatial scales?; 3) how did fishing fleet behavior change before and after the 2022 announcement of the new Hermandad Reserve?

Methods

Dataset

We used data from the international nonprofit organization Global Fishing Watch (GFW) from January 2019 to August 2023. Global Fishing Watch uses vessel movement data from Automatic Identification System (AIS) transmissions and a set of machine learning approaches to distinguish general vessel movement from different types of fishing (Kroodsma et al. 2018). The resulting records include information on the daily fishing effort, in terms of hours spent actively fishing (e.g., setting and hauling gear as opposed to being in transit), in a perimeter gridded by 0.1 degree of longitude and latitude, flag state, gear type, and additional vessel information (e.g., size, registration) (Kroodsma et al., 2018). The data only include larger (usually greater than 20 meters) vessels. Details on this dataset are best found in Kroodsma et al., 2018 and on the Global Fishing Watch website (https://globalfishingwatch.org/).

We removed the limited subset of vessels from the GMR artisanal fleet. Currently, this artisanal fleet is not well represented in the Global Fishing Watch dataset since the algorithms are not currently designed for these fleets. Thus, we only studied industrial fishing vessels (>100 tonnes), which primarily fish outside the GMR given strong enforcement.

We subsetted the Global Fishing Watch fishing effort data for the Insular Exclusive Economic Zone of Ecuador (I-EEZ, i.e., Ecuador's EEZ around the Galapagos Islands), which includes the Galapagos Marine Reserve (GMR), and the newer Hermandad Marine Reserve (HMR) (Fig. 1).

Analyses

We examined trends over time for fishing by Ecuadorian and foreign fleets at various spatial scales. We also studied how fishing effort by different gear types changed over time. We used a set of generalized linear models with Poisson error distributions to examine trends in fishing effort over time. We accounted for seasonality in fishing with a combination of sine and cosine terms. We verified all model assumptions by visually inspecting residual plots. We ensured covariates were not significantly correlated (>0.7) and the residuals were not overdispersed.

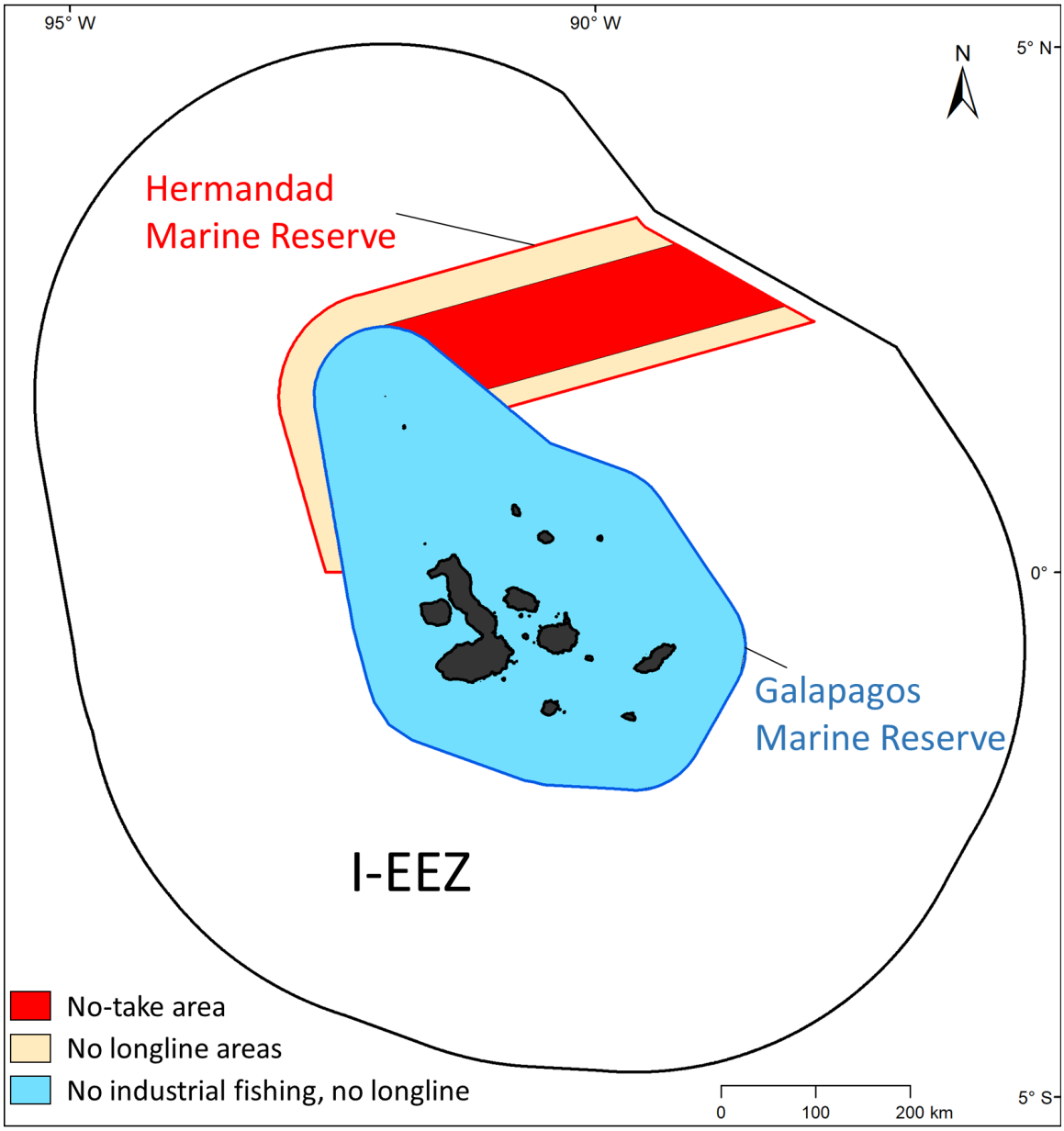

Fig. 1. Study area showing the Hermandad Marine Reserve (red contour), with no-take areas (red) and no-longline areas (light orange); the Galapagos Marine Reserve (blue contour), where no industrial fishing nor longline are allowed; and the insular EEZ (I-EEZ) with a black contour.

Results

Across the entire Ecuadorian Insular Exclusive Economic Zone (I-EEZ) around the Galapagos Island, we documented 64,626 hours of fishing by 145 unique vessels between 2019 and 2022 (Figs. 2,3). Most (92.3%) of this fishing effort was by Ecuadorian vessels from the mainland, but we also observed fishing effort by vessels from Panama, Venezuela, Great Britain, the USA, and limited effort by other countries. Total fishing effort by Ecuadorian vessels was split between

tuna purse seines (46.6%) and drifting longlines (48.2%) whereas 99% of fishing effort by foreign vessels was tuna purse seining. Effort by longliners has remained consistent over time, but tuna purse seine effort peaked in 2021 and has a more strongly seasonal pattern. Most fishing effort was concentrated in the Southwest and Northern parts of the I-EEZ (Fig. 3). Less than 1% of the total fishing effort by the large vessels studied here occurred within the Galapagos Marine Reserve.

The Hermandad Reserve was officially declared on January 14th, 2022. Almost all of the fishing within the Hermandad Reserve prior to its implementation was drifting longlines or tuna purse seines (Figs. 4,5). In 2021, only 8% of the fishing within the I-EEZ was within the Hermandad Reserve area. There was an 88% decrease in fishing effort within the Hermandad protected area after its implementation at the start of 2022. This effort doesn't appear to have shifted elsewhere as total fishing effort in the Ecuadorian Insular Exclusive Economic Zone (I-EEZ) in 2022 was less than in 2021. In addition, any remaining fishing effort in 2022 was by ECU vessels as opposed to foreign boats. From 2020 to 2021, there was a 73% increase in fishing effort in the region of the future Hermandad Reserve compared to only a 56% increase in the rest of the I-EEZ. Thus, it is possible that fishing effort increased in the area as it was being proposed.

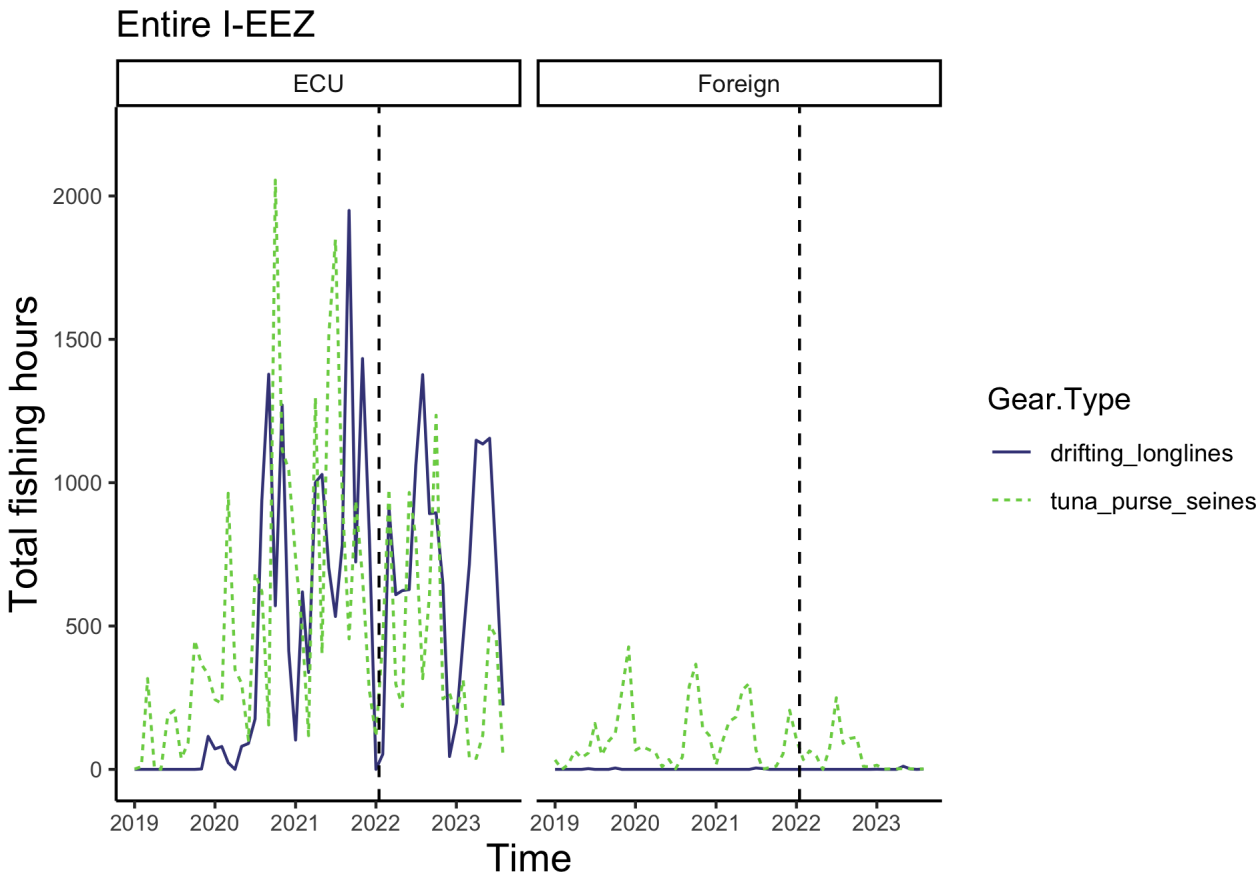

Figure 2: Total monthly industrial fishing effort (hours) in the Ecuadorian Insular Exclusive Economic Zone (I-EEZ) for different gear types for the Ecuadorian (ECU) versus all foreign fleets. The vertical dashed line indicates the announcement of the new Hermandad Reserve (which is 10% of the entire I-EEZ by size).

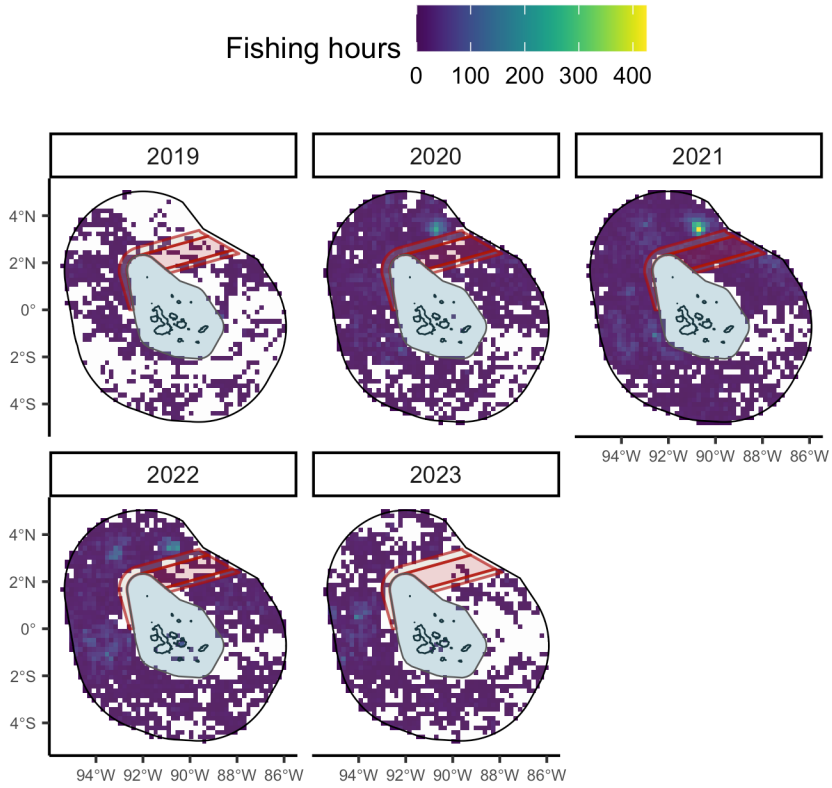

Figure 3. Total industrial fishing effort in the Ecuadorian Insular Exclusive Economic Zone (I-EEZ) over time. Non-colored cells indicate no recorded fishing activity.

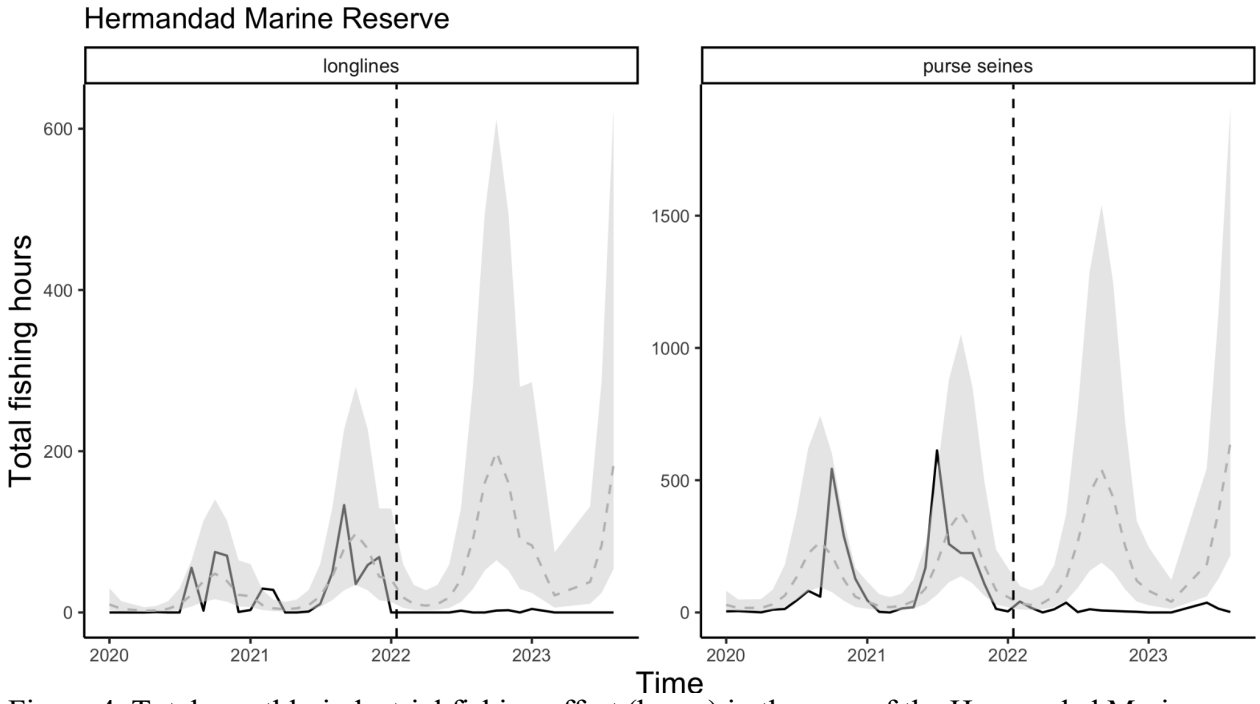

Figure 4. Total monthly industrial fishing effort (hours) in the area of the Hermandad Marine Reserve for different gear types. The vertical dashed line indicates the announcement of the new Hermandad Reserve. The fitted lighter curve indicates the line of best fit for pre-closure data projected after the closure with one standard deviation around the mean prediction. The model here is a generalized linear model with a Poisson error term with both year and month as covariates.

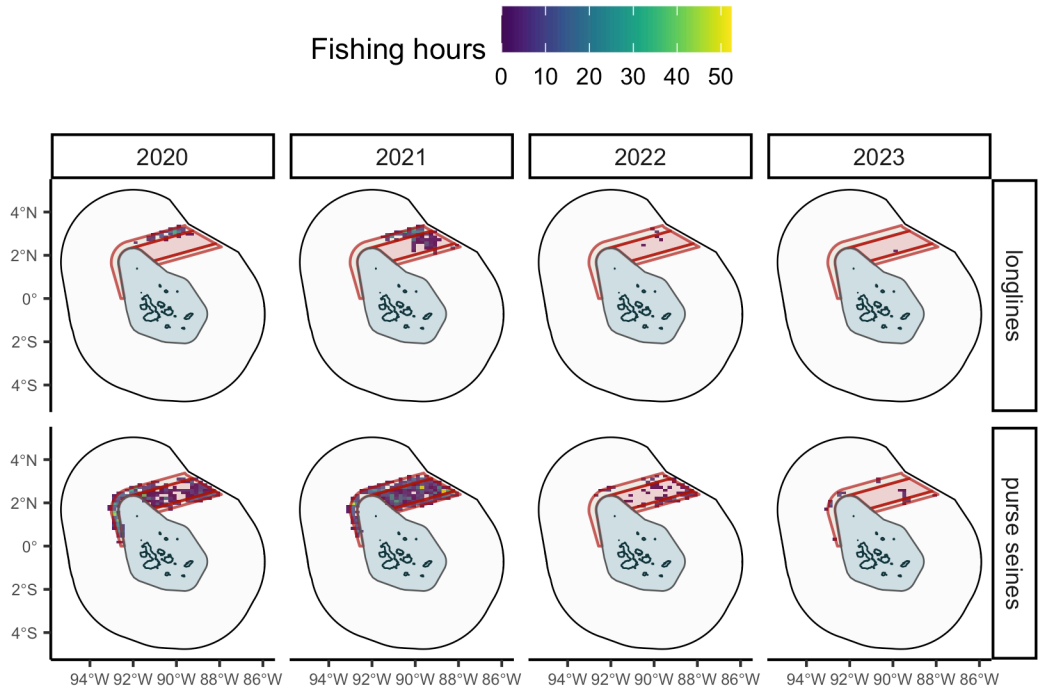

Figure 5. Total yearly industrial fishing effort (hours) in the area of the Hermandad Marine Reserve for different gear types. The reserve was announced at the start of 2022.

Discussion

We were in a unique position to study industrial fishing effort within and around a large marine protected area and to examine fishing effort before and after the implementation of a no-take area within part of a country's exclusive economic zone. From 2019-2023 (ending in August 2023), we documented 64,626 hours of industrial fishing effort around the Galapagos Marine Reserve (Figs. 2-5). The fishing within the GMR (less than 1% of effort) was primarily seining Ecuadorian vessels (Figs. S5-S7). We did not include the artisanal fishing fleet within the GMR within our analyses. Most fishing effort occurred in the northeast and in the southwest region of the I-EEZ (Figs. 3). Within the I-EEZ, most fishing (87%) was by Ecuadorian vessels. In addition, purse seining (51%), longlining (45%) were the most common types of fishing.

Our findings for the newly declared Hermandad Reserve share some similarities, but also stark differences, with past studies on the implementation of no-take areas. Previous work has noted that fishing effort can increase within a protected area when it has been announced, but not yet implemented, and this was indeed the case with the Galapagos Marine Reserve (Bucaram et al., 2018). In line with this past work, we found some evidence of a small increase in fishing effort within the Hermandad Reserve prior to the reserve declaration (Fig. 4). There was a 73% increase within the Hermandad Reserve (compared to 56% in the I-EEZ as a whole) in the year prior to its implementation.

We also documented an 88% decrease in fishing effort within the Hermandad protected area after its declaration at the start of 2022. The dramatic decrease was unexpected as there were no corresponding increases in enforcement. Instead, we suggest that it is possible that the well-publicized announcement of the marine protected area near a well-known existing marine reserve was sufficient to deter fishing pressure. Additionally, it has been demonstrated that other areas, along the western GMR boundary, receive more than 4-fold fishing effort density than the rest of the surrounding area (Boerder, Bryndum-Buchholz, and Worm 2017). Thus, the HMR region was more feasible to be closed to fishing than other areas of the I-EEZ. Unlike past work, fishing effort did not appear to have shifted elsewhere inside I-EEZ after the declaration of the Hermandad Reserve. Instead, total fishing effort in the Insular Exclusive Economic Zone of Ecuador in 2022 was less than in 2021 and there was no increase in "fishing along the line" around the reserve (Fig. 4). In addition, the limited remaining fishing effort in 2022 was by ECU vessels as opposed to foreign boats (Figs. S8-S9). We suggest that these findings regarding the no-take Hermandad Reserve conflicting with past work (Bucaram et al., 2018) may be the result of several factors: the worldwide spotlight on the Galapagos Islands, the heavily managed nature of the region, the agreements and arrangements made between the government and the large scale Ecuadorian fishing fleet during the negotiation process prior the Hermandad MPA declaration, and the distribution of fishing efforts within the protected region and in other areas of the I-EEZ prior to implementation of the HMR (in 2021, only 8% of the fishing in the I-EEZ was within the HMR). Additionally, throughout the duration of the study period, the Ecuadorian purse seine and longline fleets were participating in a Fisheries Improvement Project, in an attempt to obtain a Marine Stewardship Council (MSC) Blue Fish Label (see https://www.msc.org/en-us) as a response to the European Commission's issuance of a yellow card for illegal, unreported, and unregulated (IUU) fishing in Ecuador (European Commission 2019). While participating in this Fisheries Improvement Project, there was likely a focus on eliminating or limiting IUU fishing. Our findings would thus support the EU carding system approach to incentivizing non-IUU fishing in Ecuador (Sumaila 2019) and, for the first time, its positive impact on compliance with fishing regulations in a recently established marine protected area.

We examined industrial fishing pressure both within and around the Galapagos Marine Reserve and Hermandad Marine Reserve. Our analyses centered only on Ecuador's Exclusive Economic Zone around the Galapagos Islands including Hermandad Marine Reserve. Future work could examine the broader context of the Eastern Tropical Pacific, including the exclusive economic zones of other countries and international waters (Enright, Meneses-Orellana, and Keith 2021), especially, as new marine protected areas are established in the region. One of the most important sources of fishing pressure in the region is the large presence of squid jigging vessels from nearby and distant countries (Martínez-Ortiz et al. 2015). Although this may capture much of the legal fishing (e.g., yellowfin tuna *Thunnus albacares* and Mahi-mahi *Coryphaena hippurus* fisheries) within the Insular Exclusive Economic Zone of Ecuador, our analyses do not account for smaller artisanal vessels. In total, we observed 15 industrial vessels fishing within the Galapagos Marine Reserve compared to 188 active vessels in the Galapagos artisanal fleet (Galapagos National Park Directorate 2021; Ramirez-González et al. 2022). In addition, our analyses did not address issues related to illegal fishing activity from distant-water fishing fleets that may have disabled their AIS systems (Welch et al. 2022). We also were not able to determine long-term trends of fishing effort within the region. Many vessels we examined have

only been included in the data recently, limiting our ability to determine if increases in effort over time are real or simply from the inclusion of more vessels. Future work would need to assess whether the initial trend of compliance with the newly created Hermandad Marine Reserve is maintained over time. Future work could also examine ecological outcomes from the changing patterns in fishing effort. Recent work has highlighted the possibility of connecting satellite-based measures of fishing effort to actual catch (Willette et al. 2021; Campos et al. 2023) which will allow for mapping of catches and a more thorough understanding of the fishing patterns and potential conservation consequences. Additional fisheries independent surveys in the region could also address the ecosystem-level questions. Our work also highlights that incorporating social factors into marine spatial planning (Baker-Médard, Gantt, and White 2021; Baker-Médard et al. 2021; Cisneros-Montemayor and Vincent 2016; Cisneros-Montemayor et al. 2019) may also improve management outcomes, but further work is needed in this area.

Conclusions

We documented 66,000 hours of industrial fishing effort from 2019-2023 within the Insular Exclusive Economic Zone of Ecuador (I-EEZ) surrounding the Galapagos Archipelago. Almost all (99%) of this effort was outside the Galapagos Marine Reserve, highlighting the strong enforcement, which only allows Galapagos artisanal vessels to fish in the reserve. There was a small increase in fishing effort in anticipation of the Hermandad Marine Reserve being announced. However, there was an 88% drop in fishing effort in the year after Hermandad's announcement despite no concurrent increase in enforcement. This unprecedented compliance with a new marine protected area points to the importance of a consensus-building approach between scientists, government officials, and fishers. It also demonstrates the positive impact of sustainable fishing policies from major markets on behavioral change in the industrial fleet. In addition, existing well-enforced marine protected areas in the region, e.g., the Galapagos Marine Reserve, may have had a carry-over effect in driving high compliance. This work also highlights the importance of satellite-based estimates of fishing effort in regions where other proxies are not available or there is a concern regarding IUU fishing. Future work could explore fishing effort and MPA compliance throughout the Eastern Tropical Pacific. In addition, future work could ground-truth satellite-derived fishing vessel data and to calibrate machine learning algorithms to the artisanal fleet inside the GMR.

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Data and code availability

All data used in this paper is publicly available via the Global Fishing Watch website. We also include code and data used in this project at https://github.com/QuantMarineEcoLab/hermandad-galapagos-fishing

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