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The COVID-19 pandemic has altered illegal fishing activities inside and outside a marine protected area

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The global COVID-19 pandemic has presented a unique opportunity to explore the consequences of illegal exploitation on wildlife communities, as it continues to have wide-reaching impacts on multiple sectors, including local and national economies, international trade, and conservation enforcement[1]. The ongoing reductions in monitoring and enforcement during the pandemic have allowed increased opportunities for illegal, unreported, and unregulated activities, particularly for small-scale fisheries[2]. Even before the pandemic, policymakers and fisheries managers intent on controlling illegal fishing activities established marine protected areas (MPAs) that restrict or prohibit fishing[3]. Unfortunately, non-compliance with MPAs is often the rule rather than the exception, and less than 10% of the world's MPAs have managed to effectively reduce infringement[4]. The COVID-19 pandemic has exacerbated these management challenges: a recent review of MPAs worldwide has revealed a general decline in tourism revenue to operate park services during the pandemic, especially revenue needed for supporting personnel to monitor, patrol, and enforce restrictions[2]. Here, we compile infraction records of illegal fishing activities by both professional (commercial) and amateur (recreational) boats inside and outside of the Tupinambás Ecological Station and the Alcatrazes Wildlife Refuge (Figure 1A), notable for its high reef-fish biomass and diversity in the Southwestern Atlantic[5]. We show that illegal exploitation has shifted since the onset of the pandemic, targeting larger, higher-value species that contribute disproportionately to the structure and function of reef-fish communities in the region.

Overall, enforcement increased slightly but non-significantly during the pandemic: $n = 52$ patrols for the period from 2020–2021 versus $n = 32$ from 2017–2019 ($t_{4.13} = -2.8$, $P = 0.08$). Each patrol was performed by a single vessel with a crew of six. Despite the statistically equivalent levels of enforcement, the number of patrols that intercepted illegal activities nearly doubled from the pre-pandemic period compared with the time since the beginning of the pandemic ($n = 9$ versus $n = 17$). A total of 39 species were illegally harvested over the 5-year study: of these, 25 species were captured before the pandemic started and 27 since (Data S1). The number of threatened species captured during the pandemic by both professional and amateur boats increased from five to eight, and these were mainly elasmobranchs (Figure 1B,C).

A total biomass of 2,775 kg was recovered over the entire 5-year period by both professional and amateur boats, with the total illegal catch doubling from 853.1 kg caught before 2020 to 1,922 kg from 2020 onward. The role of professional boats in these

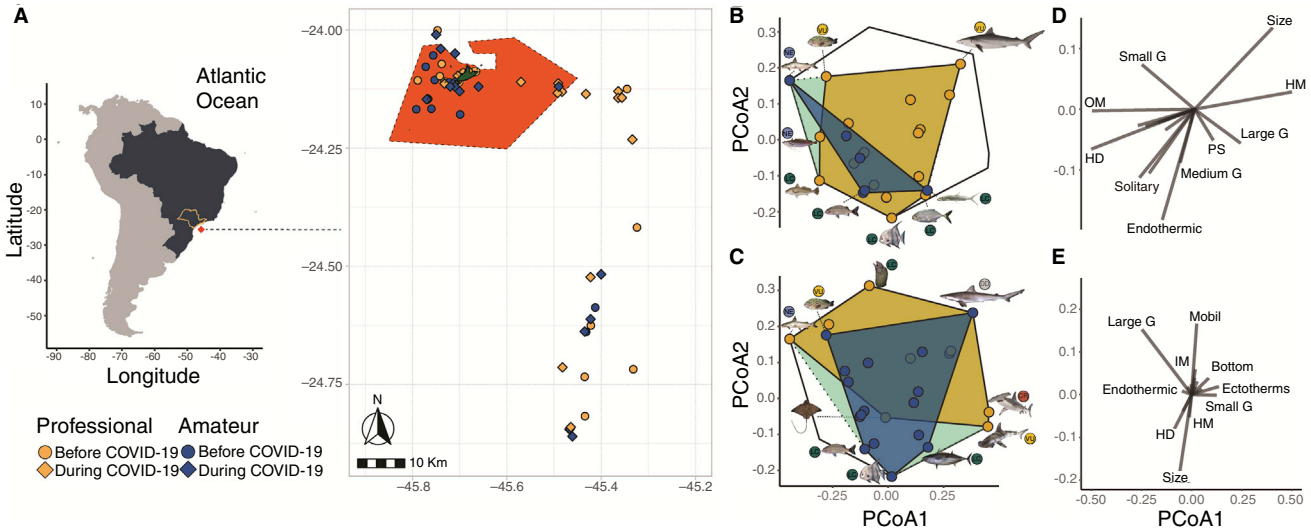

Figure 1. Illegal fishing in the Alcatrazes Archipelago 2017–2021.
(A) The spatial distribution of illegal fishing records within the Alcatrazes Archipelago between 2017 and 2021. The red dashed polygon represents the Marine Protected Area. (B,C) Plots of the multidimensional functional space occupied by species captured (B) before and (C) during the COVID-19 pandemic. The polygon in black represents the total functional space comprised by all species captured during both periods; the cyan polygon represents the functional space captured before and during the pandemic; the orange polygons represent the species captured by professional boats; the blue polygons represent the species captured by amateur boats. (D,E) The first and second axes derived from a Principal Coordinate Analysis (PCoA) performed on six traits showing the major axes of trait variation before (D) and during (E) the pandemic. Diet abbreviations: HD, herbivores-detritivores; HM, macroalgae-feeder; IM, mobile invertebrate feeders; PS, piscivores; OM, omnivores. Size group abbreviations: Small G, small group; Medium G, medium group; Large G, large group.

infractions declined inside the MPA during the pandemic, with 797.1 kg biomass of illegal catch recovered from these vessels before versus just 10 kg during the pandemic. In contrast, amateur boats generally captured a higher biomass and diversity of species during the pandemic than before (Bayesian model biomass, $\beta_B = 5.42$ with 95% credible interval [4.55, 6.56]; richness, $\beta_B = 1.67$ [0.50, 2.91]; Figure S1A–D). Most of this biomass was caught inside the MPA, with a 20x increase in illegal catches recorded during the pandemic (from 56.0 to 1,140.4 kg).

Recreational fishers greatly increased both the taxonomic and functional breadth of their illegal harvest (Figure 1B,C), expanding to incorporate formerly unfished top and meso-predators that were previously targeted only by professional vessels. In contrast, professional vessels shifted their take to include hammerhead sharks and eels. Previously, both professional and amateur fishers illegally targeted mostly invertebrate feeders and piscivores with high mobility that form medium and large biomass aggregations, demonstrating intentional switching on the part of illegal fishers to target species with higher commercial value and large body size (Figure 1D,E). This pattern of 'trophy' fishing has been observed in other conservation areas in northeastern Brazil[6] and can be associated with the higher price of large, threatened species meant to offset pandemic-driven economic losses[7], on top of the generally low monthly salary for fishers in Brazil (~$US 200 mo^{-1}).

Reductions in predator and large herbivore populations during the pandemic can release lower trophic levels, leading to cascades that alter fish community structure and convert habitat dominated by coral communities to ones dominated by fleshy algae with a low resilience to other anthropogenic impacts[8]. We also noted an increase during the pandemic in the capture of large endemic parrotfish *Sparisoma amplum*, which have been identified as important macroalgal consumers[9]. We hypothesize that these species were only captured during the pandemic by vessels very nearshore in the MPA. Combined with the removal of predators, the loss of key herbivores would further exacerbate the possibility of phase shifts towards macroalgal-dominated reefs.

Although this dataset is perhaps one of the most rigorous yet collected on illegal fishing during the COVID-19 pandemic, we must acknowledge that enforcement is limited (in this case, to a single vessel) and likely underrepresents the total amount of illegal landings. Nevertheless, we have no reason to believe that the vessels in our dataset reflect a biased subset of these illegal activities. Moreover, the designation of inside versus outside the MPA was determined by where the illegal harvest was seized, but not necessarily caught. As many vessels will flee the area before surrendering their capture, it is possible that more biomass was extracted inside the MPA than reflected here.

The COVID-19 pandemic is perhaps the most disruptive event in recent history and has been called the 'great human confinement experiment'[10]. Consequently, illegal activities have intensified in both terrestrial and marine habitats[2]. Our study documents a higher occurrence of illegal extraction of increasingly high-value species within a highly diverse MPA during the pandemic. This increase can be associated with the proximity of the MPA to the mainland, favoring smaller recreational vessels that are less detectable and echoing other examples where the pandemic has led to bolder actions by poachers to encroach further into protected reserves[2]. We present some suggestions to reverse these impacts: the use of drones, social media, and the 'Automatic Identification System' are some tools that can increase patrol effort in the field[4]. The eventual return of the tourism industry can provide renewed revenue to fund enforcement operations. Thus, although we describe a situation in which the pandemic has compromised conservation goals in just a short period, we view this outcome as an opportunity to better plan, strategically monitor, and enforce protection into the future.

SUPPLEMENTAL INFORMATION

Supplemental information includes one figure, one table, experimental procedures, acknowledgments, author contributions, and supplemental references and can be found with this article online at https://doi.org/10.1016/j.cub.2022.06.030.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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