Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Trade and governance drive luxury seafood serial exploitation

Leonardo Feitosa

lmfeitos@gmail.com

University of California, Santa Barbara https://orcid.org/0000-0002-1988-5326

Christopher Free

University of California Santa Barbara https://orcid.org/0000-0002-2557-8920

Darcy Bradley

UC Santa Barbara

Jessica Gephart

University of Washington https://orcid.org/0000-0001-6836-9291

Steven Gaines

UC Santa Barbara https://orcid.org/0000-0002-7604-3483

Article

Keywords: Shark fins, Fish maw, wildlife trade, unregulated fisheries

Posted Date: February 12th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8681552/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: There is **NO** Competing Interest.

Trade and governance drive luxury seafood serial exploitation

Leonardo Manir Feitosa[1*], Christopher M. Free[1,2], Darcy Bradley[1,3], Jessica A. Gephart[4], Steven D. Gaines[1]

1. Bren School of Environmental Science and Management, University of California, Santa Barbara, Santa Barbara, California, USA
2. Marine Science Institute, University of California, Santa Barbara, Santa Barbara, California, USA
3. The Nature Conservancy, California Oceans Program, Santa Barbara, California, USA
4. University of Washington, School of Aquatic and Fishery Sciences, Seattle, WA, USA

Corresponding author: Leonardo Manir Feitosa (lmfeitos@gmail.com)

Abstract

Exploitation of species for luxury consumption has occurred for centuries. Luxury products are perceived as high quality status symbols, driving strong demand, low supply, and high prices. These features commonly fuel unregulated markets and harvest expansions to include new species and geographies. Yet, the drivers of such serial exploitation remain unknown. Here, we identify the drivers of serial exploitation of aquatic species for luxury trade, focusing on sharks for fins and teleosts for fish maw (gas bladders). We then predict which species and countries are likely to enter the luxury seafood market next. We find that the magnitude of bilateral trade and country-level rule of law are the strongest drivers of serial exploitation. We predict that nine species of sharks and 14 species of teleosts are likely to be luxury targets by 2030, providing actionable guidance for preemptive interventions to avoid future overexploitation.

Keywords: Shark fins, Fish maw, wildlife trade, unregulated fisheries.

Main text

Exploitation of species for luxury consumption is a major driver of extinction risk. Luxury goods are commonly understood to have high demand, limited supply, and high prices[1,2]. In economic terms, they have small, or even positive, income elasticities of demand (i.e., price increases cause small declines or even positive increases in demand)[3,4]. Their high demand is driven by their ability to elevate social status, which fuels unsustainable exploitation in the absence of adequate regulation[5], creates markets for new species under international wildlife trade[5], and expands the geographical footprint of overexploitation to geographies with minimal previous harvests[6,7].

Harvests of luxury aquatic products can foment illegal, unregulated, and unreported (IUU) fishing, and quickly deplete fish populations[7]. Shark fins and fish gas bladders (hereafter referred to as fish maw) are among the most valuable luxury seafood products by weight, reaching up to US\$2,300 kg^{-1} and US\$6,830 kg^{-1} respectively[8,9]. The shark fin market has been historically regarded as the major driver of global population declines of sharks[10], while the fish maw market has caused substantial declines for select teleost species and their associated bycatch[8]. Declining abundance (supply) and increasing demand enable prices to rise faster than harvesting costs[11]. While this condition alone can drive these populations to extinction, their catch in multispecies fisheries and the synergy between their low-productivity life histories and opportunistic bycatch further enhance their extinction risk[12,13]. Additionally, consumers often place higher demand on rarer species[14], further fueling price increases and the marginal profit of fishing another individual. Here, we predict which new shark and teleost species are likely to become exploited for luxury seafood and which countries will develop fisheries for them. This information better-positions decisionmakers to proactively prevent overexploitation and potential extinctions.

We explore multiple species- and country-specific features that could potentially drive serial exploitation patterns for shark fins and fish maw. To achieve this, we use a range of phylogenetic models and ordered forest models to evaluate several potential drivers of species presence in current global luxury markets and the temporal patterns of their serial exploitation by different countries. Drawing on insights from the observed decadal patterns of exploitation from 1950 to 2019, we hypothesize that serial exploitation could be affected by five potential drivers: (1) more desirable products (i.e., larger shark fins and larger fish maws) are exploited first, which may have a strong phylogenetic association across species; (2) species more easily accessible to fishing (i.e., occurring in shallower water and having broader geographic distributions) are exploited before their deeper-occurring or geographically limited counterparts[15]; (3) supplying countries geographically closer to the end-market countries develop fisheries before countries further away[16]; (4) supplying countries with higher bilateral trade with the end-market countries develop fisheries before supplying countries with lower historical trade[17], and (5) supplying countries with weaker rule of law develop fisheries for the species demanded before those with stronger rule of law[18]. Building on the findings of these historical analyses, we then predict species and countries that are likely participants in future serial exploitation. These predictions identify high priorities for future preemptive conservation, trade, and fisheries management efforts to limit new overexploitation. To bolster these future efforts, we also use recent bilateral trade data from 2012 to 2019 for each product to assess what current data reporting limitations (e.g., poor taxonomic resolution) by exporting countries create potential barriers to curbing future IUU fishing for luxury seafood.

Results

Serial exploitation for shark fins and fish maw increased over the last 70 years

The number of countries reporting fisheries for sharks and teleosts known to be consumed as luxury seafood increased 54.1% and 48.1% from 1950 (n_{sharks} = 72; $n_{teleosts}$ = 104) to 2019 (n_{sharks} = 111; $n_{teleosts}$ = 154), respectively. Countries reported landings of 58 shark species in 1950 and this number grew to 73 in 2019 (25.8% increase). The number of teleosts consumed in the fish maw trade grew more modestly, from 51 species landed in 1950 to 59 in 2019 (15.7% increase) (Supplementary Figure S1). Over this period, most individual countries more than doubled the number of species exploited for each product (Supplementary Table S1), despite relatively modest increases overall. Although landings reporting improved over this time, partially contributing to this observation, improvements in reporting are modest compared to the diversification of exploited luxury species, with only 58.1% of the 227 species known to be exploited for luxury seafood across products.

Phylogeny and fisheries accessibility are strong predictors of presence in the luxury market

Species' presence in the luxury seafood market is significantly correlated with the phylogenies of sharks (D = 0.161; $p < 0.001$) and teleosts (D = 0.743; $p < 0.001$) (i.e., closely related species are more likely to be in the market than their counterparts). Based on the phylogenetic logistic regression models, shark species with larger total high value fin area (i.e., first dorsal and pectoral fins, and lower caudal fin lobe; β = 0.71; $p < 0.001$) and larger total low value fin area (i.e., second dorsal, pelvic, and anal fins; β = 0.63; $p < 0.001$) are more likely to be present in the shark fin market, whereas teleost species with larger volumes are more likely to be consumed for fish maw (β = 1.24; $p < 0.001$) (Figure 1A-C). We predict that nine shark species and 14 teleost species not currently exploited for fins nor fish maw have a > 50% chance of becoming exploited by future markets. This would represent a 8.2% increase in the number of shark species in the fin market, and a 12.8% increase in the number of species exploited for fish maw.

Using this phylogenetic model, we found that more desirable shark species categorized as Near Threatened, Vulnerable, and Endangered are more likely to be in both high and low value fin markets, while no clear trend seems to exist regarding conservation status and likelihood of being exploited for the fish maw market (Figure 1D-F). Instead, unassessed teleost species are the most likely to be exploited for fish maw, irrespective of desirability. Similarly, more desirable shark species inhabiting shallow and intermediate depths are more likely to be in both high and low value fin markets, while only shallow water teleosts show a positive trend towards being consumed in the fish maw market (Figure 1G-I). Similarly, sharks and teleosts with larger geographical distributions and desirability are more likely to be present in their respective luxury seafood markets (Figure 1J-L).

International trade and governance drive serial exploitation for shark fins and fish maw

Trade level and governance are the most important predictors of when a country begins exploiting sharks and teleosts for the luxury seafood market, while species' desirability and accessibility are not strongly associated with serial exploitation patterns (Figure 2, Supplementary Figure S2). For both products, exporting countries with stronger historical trade relationships with importing countries were more likely to develop fisheries for demanded species earlier than those with weaker trade relationships. We also found that older fisheries for both products started in countries with smaller fishing fleets. For fish maw, older fisheries were more likely to exploit species occurring at shallower median depths, and newer fisheries tended to exploit species occurring deeper. As decades passed, trends reversed for some predictors for both products. Newer fisheries became more likely to be developed in countries with weaker trade relationships and larger fishing fleets. Strength of governance strongly, but inconsistently, predicted the presence of shark and fish maw products in trade, with fisheries for fish maw in the 1980s and for shark fins in the 1990s being more likely to be found in countries with stronger rule of law. We found similar inter-decadal shifts in the rule of law signal for all sensitivity analyses performed on model fitting parameters (Supplementary Figures S3-5). Generally, fisheries developed in the 2010s occurred in countries with significantly lower rule of law for both products.

The future of shark fin and fish maw exploitation

Using the ordered forest model, we predict the number of species exploited for fish maw and shark fins to increase from 227 to 250 species (10.1%; 23 species), while the number of countries reporting fisheries for sharks is expected to increase from 109 to 117 (7.3%) and for teleosts from 153 to 156 (1.9%) by 2029. We predict that five new countries will enter the fish maw market, while seven will enter the shark fin market. Future exploitation for shark fins and fish maw will likely be more species diverse in select countries in Southeast and Western Asia, Central and South America, and Africa (Supplementary Figure S6A-B). In 2019, the countries with the highest number of reported species landings exploited for fish maw were Brazil (n = 13), China (n = 13), Pakistan (n = 11), France (n = 10), and Suriname (n = 10) (Figure 3A), while Australia (n = 40 species), Spain (n = 21), United States (n = 17), Panama (n = 15), and Brazil (n = 14) exploited the highest diversity of sharks (Figure 3B). In the following decade, we predict that Myanmar (n = 14 new species), Venezuela (n = 14), Bangladesh (n = 13), Guinea-Bissau (n

= 9), and Oman, Togo, Solomon Islands, and Seychelles (n = 8) will have the largest increase in diversity of species exploited for fish maw (Figure 3C). For shark fins, we predict that United Arab Emirates (n = 35 new species), South Africa (n = 29), Venezuela (n = 20), Timor-Leste (n = 20), and Fiji (n = 16) will be the countries with the largest increase in diversity of shark species exploited (Figure 3D). All countries with increases in the number of species exploited for each product are shown on Supplementary Figure S7. Since it is unlikely that any of the fisheries reporting landings in 2019 will stop fishing by 2029, we consider that the number of species currently exploited in each country will not decrease, and provide an overall number of species we predict will be exploited by 2029 for fish maw (Figure 3E) and shark fins (Figure 3F). However, increases do not correspond to a proportional rise in the number of species exploited for each product. For example, we predict no new species of shark becoming exploited in Brazil, but predict the addition of three species exploited for the fish maw market.

Our model reveals likely future hotspots of exploitation for these luxury seafood products (i.e., countries above the 95% quantile for number of species exploited). Venezuela, Bangladesh, South Korea, China, Suriname, Myanmar are predicted to become diversity hotspots for fish maw exploitation. For shark fins, Australia, South Africa, United Arab Emirates, Venezuela, the United States are future hotspots. When both products are combined, Venezuela, Australia, United Arab Emirates, South Africa, United States, South Korea, Spain, Brazil, Portugal, United Kingdom, and Japan stand out as hotspots for future luxury seafood exploitation in terms of species diversity (Supplementary Figure S8). All projected species to be exploited by country and market are listed in Supplementary Table S3.

Although we demonstrate that several countries will likely have a substantial increase in the number of species exploited, not all species have the same likelihood of becoming exploited (Figure 4). For example, among the shark species currently not reported by Fiji at the species level, the blacktip shark (*Carcharhinus limbatus*) has the highest probability of exploitation (67.8%) while the crocodile shark (*Pseudocarcharias kamoharaii*) is just above the 50% cutoff for future exploitation. Likewise, the same species have different probabilities of being exploited by each country (e.g., 65.5% chance of grey reef shark (*C. amblyrhynchos*) exploitation in the United Arab Emirates vs. 50.6% chance in Thailand; Figure 4, Supplementary Figure S9). We observed a similar pattern for the species predicted to be exploited for fish maw. Among the species of teleosts currently not reported by fisheries in Venezuela, the smallscale weakfish (*Cynoscion microlepidotus*) has the third highest probability of being exploited (76%) compared to the Atlantic goliath grouper (*Epinephelus itajara*; 60.2%), with the same species of weakfish having a lower probability of becoming exploited in Suriname (51.1%) (Supplementary Figure S10).

Key biological characteristics were similarly distributed between the species currently exploited and those predicted to be for each product (Supplementary Figure S11A-B). Teleosts occupying waters below 200 m deep were more likely to be exploited both now and in the future, while species with a larger body volume have the highest likelihood of being exploited in the future (Supplementary Figure S11A). For shark fins, species occupying waters between 0 and 600 m deep and with medium to large total high and low value fin areas had consistently greater chances of being exploited (Supplementary Figure S11B).

Countries with high exports report landings at high taxonomic levels

While we predict country-specific species exploitation, predictions are limited by the reporting resolution and restricted to presence in exports. Based on the country-specific fisheries landings reported from 2012 to 2019, we derived a reporting resolution index (RRI) to determine the share of the landings reported at the lowest taxonomic level. Values close to one represent countries reporting most of their landings at the species level, while those close to zero represent countries reporting most of their landings at the class level (i.e., Elasmobranchii or Actinopterygii). Some of the countries with the highest exports of shark fin and fish maw report most of their landings at the lowest RRI and are clear locations for conservation interventions and improved reporting to ensure the traceability and sustainability of exports (Figure 5). Among exporters of fish maw, Togo, Mozambique, Suriname, and Guyana stand out as those with the lowest RRI and highest exports (Figure 5A). Most of the shark fin exporters report their landings at lower taxonomic levels, but some countries with important contributions to the market also have the lowest RRI values (Figure 5B). Some of these countries are also among those we predicted to develop fisheries for species exploited in these markets (Togo, Guyana, and Suriname for fish maw; Guatemala, Indonesia, Oman, and United Arab Emirates for shark fins).

We found that countries with the highest species diversity in exploitation were not the largest suppliers of these products to the end-market countries (Supplementary Figure S12A-B). Between 2012 and 2019, the top five exporters of shark fins by mean value were Mexico, Spain, Singapore, Namibia, and Peru. For fish maw, the top five exporters by mean value were Uganda, India, Tanzania, Brazil, and Guyana (Supplementary Figure S12C). Evaluating trade amounts by quantity (instead of value), results in Denmark being the largest exporter of fish maw, followed by Vietnam, Iceland, Uganda, and Norway, while Namibia is revealed as the largest exporter of shark fins followed by Spain, Singapore, China, and Peru (Supplementary Figure S12D).

Discussion

Unlike other aquatic harvests, the income elasticities of demand typical of luxury seafood products place a stronger incentive for geographic and taxonomic expansions, leading to more overexploitation, depletion, and higher extinction risk for more species. Our findings highlight the importance of trade strength between exporting and importing countries and the rule of law in exporting countries on the development of fisheries for these products, while species desirability is comparatively a minor driver. Our analyses predict that future serial exploitation will be focused on a subset of countries in Western and Southeast Asia, Central and South America, and Africa - geographies where landings monitoring is poorer, fisheries management is weaker[19,20], and IUU fishing risk is higher[21]. Because our predictions apply to the decade between 2020 and 2029, it is likely that the species and countries predicted to enter these luxury markets may already be newly exploited though not yet present in available data.

Our results contrast with related studies of other luxury seafood products. Eriksson et al.[22] used data on the geographical distance and socioeconomic status of exporting countries to evaluate the drivers of serial exploitation patterns for sea cucumbers and found no significance in either predictor. They attributed the geographical spread of sea cucumber harvests to globalization and the growing presence of Chinese migrants outside of China. While we found limited evidence for geographical factors shaping when a country began exploiting species for luxury seafood relative to other countries, we find strong evidence for the importance of governance and economic features of the exporting countries. Despite methodological differences in the models employed, both findings underscore the minor role that geographical distance plays in determining where harvests for dried luxury seafood products occur and point to potentially distinct and product-specific drivers.

To our knowledge, this is the first study to use species-specific characteristics as predictors of their serial exploitation patterns. Despite species-specific desirability not being a significant predictor of when a species enters any of the luxury markets analyzed, desirability does have a significant effect on whether a species is present in luxury markets, providing strong evidence of the role of evolutionary history in species exploitation for aquatic species. Evolutionary history is known to predict desirability in luxury markets for terrestrial vertebrates[23,24], and may play a similar role in luxury seafood products more generally (e.g., sea cucumbers, precious corals). The lack of large-scale resolved phylogenies at the species level for invertebrates exploited for luxury seafood prevented us from extending this assessment and should be an important focus for future research.

Our findings further suggest that the pool of new substitutes for shark fins is now quite small. Although we could not include batoids in our phylogenetic logistic models due to the lack of species-specific fin morphometric data, the already widespread presence of shark-like ray species[25,26] in the fin market suggests that this group could be the next frontier for serial exploitation for fins. Additionally, given that fins from shark-like rays and other batoids often fetch higher prices than several shark species[27], exploiters might target additional batoids before the nine shark species we predict as new targets. In contrast, we found that the pool of substitutes for fish maw is much larger. Given the recent evidence suggesting that fish maw may also serve as a substitute for shark fins in the luxury seafood markets of Southeast Asia[28], we consider that this can lead to high extinction risks to the teleost species exploited for fish maw and those comprising bycatch in their fisheries also demanded for luxury seafood markets (i.e., sharks and rays), as recently shown by Amepou et al.[29] in Papua New Guinea.

We provide strong evidence for which species are already exploited and should be considered for listing under existing trade regulations, as well as those that should be preemptively listed before their populations become depleted. Of the 109 species of sharks currently exploited for fins, 74 have their international trade regulated by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), while only two (totoaba, *Totoaba macdonaldi*, and the kaluga sturgeon, *Sinosturio dauricus*) of the 92 teleost species consumed for fish maw are listed in CITES Appendices I and II, respectively. Currently, 92 shark species are listed in CITES, none of which comprise those we predict could enter the fin market. While CITES-listing does not prevent trade, and evidence of its effectiveness in decreasing illegal and unsustainable harvests is mixed[30–32], our results provide valuable information for securing future protections for species exploited for luxury markets, especially for fish maw, which have little to no protection[19].

Our work also underscores two important data gaps. First, the lack of taxonomic resolution in reported species landings impedes a more complete analysis of species exploitation risk and undermines the ability for countries to monitor, assess, and manage vulnerable species. Several countries supplying the shark fin and fish maw markets report most of their fisheries landings at the class (i.e., Elasmobranchii and Actinopterygii) or family levels, thus precluding the inclusion of a more comprehensive species list in our analysis. Second, the lack of product- (for fish maw) and species-specific (for shark fin and fish maw) trade data reporting precluded us from analyzing the relative importance of the serial exploitation drivers directly from trade data. The recent development of the Aquatic Resource Trade in Species (ARTIS) database[33] is a crucial step forward to address trade related data gaps for fished species, but the lack of requirements for species-specific trade reporting and traceability stymies the development and implementation of much needed conservation measures for these species[6,19] and enables countries to export CITES-regulated species without reporting[32].

Going forward, decisionmakers can use our projections to enact timely and targeted fisheries management and wildlife trade regulations at national and international levels. By proactively enhancing biodiversity protections, depletion of species most likely to be exploited for luxury seafood products and their bycatch could be preemptively avoided. Halting serial exploitation of these products will help avoid the past ecological and socioeconomic damages of overexploitation globally, and preserve the long-term sustainability of millenary cultural practices. Future studies employing our methods for other wildlife trade products (i.e., sea cucumbers, live reef fish for food, ornamental fish) can similarly identify which species and geographies are in need of proactive conservation to increase the sustainability of these markets.

Methods

Overview

Given the complexity and nested nature of the research questions, we follow a three-step analytical approach. First, we use phylogenetic models to evaluate if species' presence in the shark fin and fish maw markets is affected by the group's phylogeny. We then test if the distribution of species' desirability traits (i.e., total area of high and low value shark fins by species and maximum body volume for teleosts) map onto each group's phylogeny. We finish this initial step by running phylogenetic logistic regression models for each product and desirability traits to predict which new species could become a part of each market. Second, we build four datasets (one for each main importer of shark fins - China, Singapore, and Vietnam - or fish maw - China) with the year a fishery for each species of shark or teleost was developed in each country to supply each luxury market. We then match these datasets with the year- and country-specific data on the trade strength and geographic distance between exporting and importing countries, the rule of law and fishing fleet size in the importing country, and with the species desirability predictors. With these datasets, we fit a set of end-market-specific ordered forest models to identify the main drivers of serial exploitation for each product. Third, we combine the results of the phylogenetic logistic regression and the ordered forest models to predict the probability that each country develops fisheries for previously unexploited species for each product. With this analysis, we predict which species will likely become exploited next and where fisheries for them will likely develop in the next decade.

Data collection and preparation

To test these hypotheses and identify the main drivers of serial exploitation and depletion, we used published, gray literature, and personal communications with experts (Baian Lin, pers. comm.) to obtain a list of shark and teleost species recorded in shark fin and fish maw markets. In total, we identified 227 species consumed in luxury dried seafood markets, including 109 teleosts and 118 sharks consumed by the fish maw and fin markets, respectively. Given the poor taxonomic resolution and short time series of the wildlife trade data available[33], we collected species- and country-specific landings data from the Sea Around Us Project (SAUP) (https://www.seaaroundus.org/) and the Food and Agriculture Organization (FAO). Although fisheries landings time series do not directly document when a country first exports products from a species (i.e., a species may be only domestically consumed for products other than luxury), given the high level of globalization of seafood trade and our focus on species byproducts that largely support international markets, time series of fisheries landings are the best proxy data available to answer our research questions. Such a proxy has been used for similar studies targeting sea cucumbers but with no species-specific information due to poor taxonomic reporting of sea cucumber fisheries landings data[6]. With the landings data, we recorded the year when each species was first exploited in a given country as the year the fishery for that species started and thus when exports of that species are assumed to have started to supply the luxury market for that product. While both SAUP and FAO datasets report similar data, some species are only present in one or the other. Since some species and countries are also present in both datasets, we keep only the earliest record for each species-country pair, regardless of the data source. The initial dataset spanned 1950 to 2019, but we removed the first two years of landings data for all species-country pairs to remove artificial start years of exploitation.

Since the hypotheses we test include geographical, trade, biological, and socioeconomic variables, we used multiple sources to build the dataset to test them. To support the evaluation of the geographical hypothesis (i.e., more likely to trade with close countries), we collected bilateral marine distance between countries[34]. To support evaluation of the trade strength hypothesis (i.e., more likely to trade with countries with strong and existing relationships), we collected both historical[35] and current[36] trade from the *Centre d'Etudes Prospectives et d'Informations Internationales* (CEPII). The historical bilateral trade data spans from 1827 to 2014 and is reported in British pounds (GBP; 2014 values), while current bilateral trade spans from 2014 to 2020 in current USD. We then converted the trade flow in GBP to USD using the year-specific conversion rates present in the TRADHIST dataset, and used the consumer price index (CPI) to correct for inflation and obtain the bilateral trade flow in 2019 USD values.

To support the evaluation of the socioeconomic hypothesis (i.e., countries with lower socioeconomic capacities develop fisheries first), we used the country- and year-specific Rule of Law index from the Varieties of Democracy (V-Dem) Institute[37] as our governance predictor. This index ranges from 0 (lowest rule of law) to 1 (highest rule of law) and is calculated yearly for almost every country in the world based on three attributes: legality (i.e., laws apply to all, are clear, and predictable), procedure (i.e., laws are applied impartially, fairly, and follow due process), and institutional (i.e., independent judiciary, presence of checks and balances, absence of corruption in institutions, and separation of powers)[37]. Additionally, since the amount of species fished in a country will be affected by fishing effort capacity, we control for each country's capacity to fish with the estimates of each country's fishing fleet size reported by Rousseau et al.[38] for longlines, gillnets, trawls, seine nets, and handlines, which can all catch sharks and/or teleosts. These data only span from 1950 to 2017 and we repeat the 2017 values to fill in the information missing for 2018 and 2019 for each country's time series.

To evaluate the biological hypothesis (i.e., more likely to trade species with shared desirable traits), we further included species-specific morphologic variables that correlate with desirability traits for these products. For shark fins, we used fin area as the desirability metric for the two main markets: high grade (large whole fins sold individually) and low grade fins (smaller fins sold as wholesale)[39,40]. We used ImageJ to measure the mean area for each fin (i.e., first and second dorsal, pectoral, pelvic, anal, and lower lobe of the caudal fin) from each species' illustrations present in Ebert et al.[41]. These illustrations have been validated to be at scale with real life measurements[42] and have been extensively used to study shark morphology and functional diversity[43]. We followed the fin grade evaluation from Vannuccini[40] to designate high (first dorsal, pectoral, and lower caudal fin lobe) and low (second dorsal, pelvic, and anal) value fins, and then summed the areas of each fin per fin grade to calculate the total area high and low value fins for each species. For fish maw, larger gas bladders are generally considered to fetch higher prices than smaller ones[44] but data on gas bladder size is not available. Thus, we calculated species maximum volume by multiplying the maximum length, maximum body depth, and maximum body width and used it as a proxy for the size of the species' gas bladder. We consider that species with larger volumes are more likely to have larger gas bladders. We obtained maximum length, body depth, and body width estimates for each species from the FishLife R package[45].

Given that fisheries for species can only be developed if species are accessible to fishing (i.e., species occurring in shallow water are more accessible than those occurring in deeper waters), we included the median depth of occurrence for each species as a predictor to control for how accessible a species is to fisheries. These data were obtained from FishBase or IUCN Red List assessments, with preference for FishBase when both provided data. For species inhabiting freshwater ecosystems and with no depth range information available, we set the median depth of occurrence at 5 m. We then categorized these species into shallow (median depth < 100 m), intermediate (median depth between 100 and 500 m), and deep (median depth > 500 m) water inhabitants.

To predict which species would likely be exploited for fins or fish maw in the future, we first created a usable version of each group's phylogeny. Since there is no single phylogeny for teleost fish, we created a list of fish we considered likely to be exploited for fish maw based on (1) the presence of gas bladders[46], (2) maximum total lengths between 20 and 360 cm, and (3) current occurrence of congeners in the fish maw trade. We then used the FishPhyloMaker R package[47] to build a phylogeny for this final list of species, and used it in all subsequent phylogenetic analyses. Sharks have an updated phylogeny, which is available as a set of 10,000 trees[48]. We used the maxCladeCred function from the phangorn R package[49] to select the maximum clade credibility tree, which we then filtered to remove batoid and chimaera species, and used this phylogenetic tree for all subsequent phylogenetic analyses for sharks.

Given the country-specific nature of the predictions, we also needed the list of countries where each species is known to occur for serial exploitation predictions. For that, we downloaded the distribution maps from the IUCN Red List assessments for those species currently recorded in luxury consumption and for those predicted to be exploited in the future by the phylogenetic logistic regression models. We then created a 1º x 1º grid to overlay the IUCN distribution maps and transformed each of them into a grid of the same scale with the fasterize R package[50]. We extracted the names of the countries where they are known to occur based on each species' occurrence in cells within each countries' exclusive economic zone. For species with no species distribution maps, we extracted the number of countries from their IUCN status assessments or from the locations with known records from FishBase. With the list of species and potential countries, we then included the country-specific data for the predictor variables used to fit the ordered forest models. For those that change through time (i.e., Rule of Law index, trade flow, and size of the fishing fleet), we calculated the per country rate of change across the last ten years of data and multiplied the 2019 value by the resulting rate of change to project future values for 2029. For the time constant variables (i.e., maritime distance, total high and low fin areas, maximum volume, and median depth of occurrence), we used values as they were. With these data, we built the predictive dataset with potential species-country pairs that could develop fisheries for species supplying each product. Since trade flow and maritime distance are bilateral variables, we created one dataset for each consuming country as done in the inference portion of the analysis.

Phylogenetic analyses

Since our research questions have a nested nature, we needed to answer them sequentially. First, we had to establish which species could be likely substitutes for each product based on their desirable traits. For that, we performed a multistep process. We started by using the finalized phylogenetic trees from each group to test if the presence in the luxury market and the desirable traits for each product both have phylogenetic signals. Since the former variable is binary and the latter is continuous, we use specific tests for each. To test if the presence in the luxury market has a phylogenetic signal, we use the D statistic[51] and we use Pagel's λ[52] to evaluate the existence of a phylogenetic signal for total high and low value fin areas for sharks, and volume for teleosts. For these analyses, we used R packages caper[53] and phytools[54], respectively. Similar analyses have been used to evaluate which birds are traded as pets[24] and which terrestrial vertebrates are traded for multiple products[23]. Both tests are fitted to the phylogenies of each group and do not have response variables.

Second, since both shark fin variables (total high value fin area $\lambda = 0.811$, $p < 0.0001$; total low value fin area $\lambda = 0.782$, $p < 0.0001$) and teleost (maximum volume $\lambda = 0.873$, $p < 0.0001$) have strong phylogenetic signals, we can use them to evaluate the role of each group's evolutionary history on species' desirability and their likelihood of being in the market for each product. We then used a phylogenetic logistic regression model[55] to predict the probability that species would be exploited for luxury as a function of their desirable traits. From the shark and teleost species in each phylogeny, we assigned their presence or absence in the luxury seafood market based on published records. We used the model to predict the probability of each species being exploited for fins or fish maw. We then considered the species predicted to have a > 50% chance of becoming exploited for these products as potential substitutes and likely to enter the markets in the future, and thus included them in the datasets for serial exploitation prediction.

Finally, to analyze how each desirable trait interacted with species' extinction risk and the likelihood of being fished, we fitted three other phylogenetic logistic regression models. First, we fitted models evaluating the interaction between each desirable trait to species' IUCN Red List status (i.e., Near Threatened, Vulnerable, Endangered). Second, we fitted models for the interaction between each desirable trait and species' depth distribution, hypothesizing that those occurring in shallower water are more likely to be exploited than their counterparts[15]. For that, we categorized species into how accessible they were to fishing based on their depth distribution. Species with median depths of occurrence up to 100 m deep were assigned as shallow, between 100 m and 500 m as intermediate, and beyond 500 m as deep water inhabitants. Finally, hypothesizing that species occurring in more countries are also more likely to be fished and traded internationally, we calculated the interquartile range for the number of countries where each species occurred and assigned species to these low, medium, and high distribution quantiles. We then fitted models for the interaction between species' desirable traits and the geographic distribution quantiles. All model formulas and the respective research questions they are set up to answer are described in Supplementary Table S4.

Serial exploitation modeling

With the phylogenetic analyses finalized, we then moved on to the serial exploitation modeling. Due to the ordered nature of the response variable (i.e., year a country started a fishery for a given species), we used an Ordered Forest algorithm[56] with the orf R package[57], which uses random forests to perform inference and predictions for ordered response variables. Ordered Forest models are more robust to imbalanced data settings than regular parametric ordinal regression models, while still holding either similar or superior predictive power to recently developed ordinal random forest algorithms[56,58]. Another advantage of using the Ordered Forest model is that it allows for the conditional calculation of marginal effects for inference, a feature currently unavailable in other random forest algorithms for ordered response variables.

Due to the country-specific nature of the bilateral datasets (i.e., geographical distance and trade flows), these models can only be run for each consuming country at a time. To maintain the project's feasibility and real-world applicability, we selected the top three countries known to consume each product and fitted a model for each. Given the more widespread consumption of shark fins, we used bilateral trade data from the BACI bilateral trade database[59] to calculate each country's participation in the imports and exports for each product. The harmonized system (HS) trade codes for shark fins have only started being adopted in 2012, thus our calculations are an average between 2012 and 2020 by imported value and quantity. China is by far the largest importer and consumer of shark fins (63.2%), but Singapore (21.5%) and Vietnam (3.7%) are further ranked as second and third importers of shark fins globally. Since China is the only country with meaningful reports of fish maw consumption, we only fit the ordered forest model to it.

Given the imbalanced number of species-country pairs recorded for each year, we created seven 10-year bins for each country-specific dataset. By doing this, we decrease data imbalance and create a better model fit setting for both inference and prediction with no meaningful loss of statistical power. To guarantee proportional representation of each 10-year bin in the model fitting workflow for all importing countries, we split each importing country-specific dataset into 80% training and 20% testing data with stratification by bins, and scaled predictor variables. We then fitted the shark fin ordered forest model for China (n = 695), Singapore (n = 705), and Vietnam (n = 745), and the fish maw model for China only (n = 465) using the following equations:

$$P\left[Y_{m,s} = m \mid X_s = x\right] = High\ area_i + Low\ area_i + Depth_i + Distance_{e,j} + Trade_{e,j} + ROL_e + Fleet_e \quad (1)$$

$$P[Y_{m.s} = m \mid X_s = x] = Body\ Volume_i + Depth_i + Distance_{e,j} + Trade_{e,j} + ROL_e + Fleet_e \quad (2)$$

Where m are the classes in the response variable (i.e., our 10-year bins) and s are the species-country pairs. High area, low area, volume, and depth correspond to the total high value fin area, total low value fin area, maximum volume, and median depth of occurrence for species i. Given their bilateral characteristics, maritime distance and trade magnitude for each exporting country *e* are used based on their values towards importing country *j*, and rule of law index (ROL) and fishing fleet size values are expressed only for each exporting country *e*. We use equation (1) for the shark fin models and different importing countries, and equation (2) for the fish maw model. The same models are used for both inference and prediction. After model fitting, we calculated a weighted mean using the proportion of the global imports of shark fins by China, Singapore, and Vietnam to obtain a single estimate and standard error for each predictor and decade for the shark fin models.

To ease the interpretation of inference results and whether they validate the hypotheses, we simulated datasets that would intentionally confirm each of the hypotheses for each product. For this simulation, we relied on the same datasets used to fit the shark fin and fish maw ordered forest models with China as the importing country. We then simulated data for each predictor to match the expected direction of each hypothesis (i.e., trade magnitude is distributed in decreasing order across decades) by deriving a normal distribution centered around the mean from the observed data. This starting value then shifted along the hypothesized trend under the standard deviation from the observed data to avoid complete separation for each decade. We then fitted univariate versions of the model for each predictor. This procedure demonstrates what result we should expect for each product if each hypothesis was true. We then compared the simulated results to those obtained from the observed data to qualitatively evaluate which hypotheses were confirmed and interpret how they differed from the expected inference values.

While the ordered forest model's predictions with inference were overall good, fitting the models specifically for prediction substantially increases the model performance (Supplementary Table S5). Therefore, we chose to fit the prediction-only models to the same data following the same data splitting procedure, but now with the inference arguments turned off. For the fish maw model, we followed a 70% training and 30% testing data split due to better accuracy. We then use these models to predict the probability of each country developing a fishery for each species and product. We continue to follow the country-specific nature of the study design, but since these species are traded globally we consider it would be irrelevant to have a probability applied to each consuming country individually. Thus, we calculated the weighted mean probability per product across consuming countries following the same weights used for inference and used this value as the final probability that each country will develop a fishery for a given shark species targeting the fin market. Since fish maw is only significantly consumed in one country, we calculated the median probabilities for each species-country pair. For all products, we considered species-country pairs with > 50% chance of being present as likely to become future suppliers of these luxury markets. With these results, we sum the number of species predicted to be exploited by country and product to obtain the future hotspots of exploitation for luxury seafood.

Trade data analyses

While trade data reported at the species level would be ideal for our study, shark fin and fish maw trade aggregates species, and depending on the Harmonized System version, are aggregated with other fishery products. As such, reported trade data does not provide the necessary resolution or time span for our evaluation of historical serial exploitation patterns. Nevertheless, we used trade data on shark fins and fish maw to put our serial exploitation results into context in two ways. First, we used the BACI data to calculate the mean quantity and value of exports to the most important end-markets by exporting and importing country pairs between 2012 and 2019. Second, we bridged the mean quantity exported by each country to each end-market of interest with the taxonomic level of landings reporting from each country to better understand which are the potentially high concern countries where a wider diversity of species might already be unknowingly exploited due to poor taxonomic resolution in the fisheries landing data. For that, we calculated the reporting resolution index (RRI), a metric that quantifies in what taxonomic detail countries last reported their landings. To calculate the RRI, we filtered the aggregated landings dataset from the FAO to include country-specific landings from 2012 to 2019 and assigned a taxonomic classification (i.e., species, genus, family, order or class) to each observation per country and group (sharks or teleosts). We do not use the SAUP data for this analysis because our intent is to evaluate the actual catch reporting by the actual countries, rather than catch reconstructions by a third party. We then summed landings per country and taxa, and calculated the share of the landings reported by country for each taxonomic level. We then assigned penalties to each level of taxonomic reporting, with species level getting a penalty of 1 followed by decreasing penalties at 0.25 intervals for the subsequent higher taxonomic levels until 0.01 for reporting at the highest level – class. We then calculated the RRI for exporting country *e*, importing country *j*, and product *p* with the following equation:

$$RRI_{j,e,p} = \Sigma(Share_e \times Penalty) \quad (3)$$

Given the importance of reporting landings at the species level to curb IUU fishing and to fulfill international wildlife trade agreements, countries that are important traders and report landings at low taxonomic resolutions are at higher risk of undergoing IUU fishing. We then divided the countries into tertiles for RRI and the amount of each product exported. Countries at the lowest tertile for the RRI and the highest tertile for exports as being at critical risk of IUU fishing, and are potential key areas for serial exploitation towards luxury seafood products.

Acknowledgements

We thank Dr. David Tilman for providing thoughtful guidance on improving this work, Stanley Shea for facilitating an *in loco* experience in Hong Kong's dried seafood markets, Dr. Yvonne J. Sadovy for sharing her perspective on the fish maw trade, Dr. Jorge Nunes for providing advice on teleost morphometrics, Dr. Liu Min and Baian Lin for providing a list of species found in the fish maw trade, and Hayden Vega for the assistance in collecting morphometric measurements for shark fins. LMF was funded by CAPES and Fulbright Brazil under project number 001, the Arnhold Foundation, the Schmidt Family Foundation, and the World Wildlife Fund (WWF) through the Russell E. Train Fellowship. J.A.G. was supported by the US National Science Foundation (#2504715).

Data and code availability

All datasets built and necessary to run the analyses are deposited in Dryad[60], and the code repository is available at Zenodo (**10.5281/zenodo.18141506**).

References

1. Grewe, B.-S. & Hofmeester, K. Introduction: Luxury and global history. in *Luxury in Global Perspective* (eds Hofmeester, K. & Grewe, B.-S.) 1–26 (Cambridge University Press, 2016). doi:10.1017/9781316257913.001.
2. van Uhm, D. P. The social construction of the value of wildlife: A green cultural criminological perspective. *Theoretical Criminology* **22**, 384–401 (2018).
3. Kapferer, J.-N. Abundant rarity: The key to luxury growth. *Business Horizons* **55**, 453–462 (2012).
4. Mundel, J., Huddleston, P. & Vodermeier, M. An exploratory study of consumers' perceptions: What are affordable luxuries? *Journal of Retailing and Consumer Services* **35**,

68–75 (2017).

5. Rawson, K. & Hoagland, P. Sea cucumbers in a pickle: the economic geography of the serial exploitation of sea cucumbers. *E&S* **24**, art35 (2019).
6. Anderson, S. C., Flemming, J. M., Watson, R. & Lotze, H. K. Serial exploitation of global sea cucumber fisheries. *Fish and Fisheries* **12**, 317–339 (2011).
7. Berkes, F. *et al.* Globalization, Roving Bandits, and Marine Resources. *Science* **311**, 1557–1558 (2006).
8. Ben-Hasan, A. *et al.* China's fish maw demand and its implications for fisheries in source countries. *Marine Policy* **132**, 104696 (2021).
9. McClenachan, L., Cooper, A. B. & Dulvy, N. K. Rethinking Trade-Driven Extinction Risk in Marine and Terrestrial Megafauna. *Current Biology* **26**, 1640–1646 (2016).
10. Dulvy, N. K. *et al.* Extinction risk and conservation of the world's sharks and rays. *eLife* **3**, e00590–e00590 (2014).
11. Courchamp, F. *et al.* Rarity Value and Species Extinction: The Anthropogenic Allee Effect. *PLOS Biology* **4**, e415 (2006).
12. Burgess, M. G., Polasky, S. & Tilman, D. Predicting overfishing and extinction threats in multispecies fisheries. *Proceedings of the National Academy of Sciences* **110**, 15943–15948 (2013).
13. Feitosa, L. M., Burgess, M. G., Free, C. M. & Gaines, S. D. Synergies between price and life history enhance extinction risk in open-access fisheries. *Fish and Fisheries* **25**, 972–984 (2024).
14. Gault, A., Meinard, Y. & Courchamp, F. Consumers' taste for rarity drives sturgeons to extinction. *CONSERVATION LETTERS* **1**, 199–207 (2008).

15. Dulvy, N. K. *et al.* Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. *Current Biology* **31**, 4773-4787.e8 (2021).

16. Sadovy, Y. Trouble on the reef: the imperative for managing vulnerable and valuable fisheries. *FISH AND FISHERIES* **6**, 167–185 (2005).

17. Morcatty, T. Q. *et al.* Illegal trade in wild cats and its link to Chinese-led development in Central and South America. *Conservation Biology* **34**, 1525–1535 (2020).

18. Liew, J. H. *et al.* International socioeconomic inequality drives trade patterns in the global wildlife market. *Sci. Adv.* **7**, eabf7679 (2021).

19. Sadovy de Mitcheson, Y. *et al.* Out of control means off the menu: The case for ceasing consumption of luxury products from highly vulnerable species when international trade cannot be adequately controlled; shark fin as a case study. *Marine Policy* **98**, 115–120 (2018).

20. Simpfendorfer, C. A. & Dulvy, N. K. Bright spots of sustainable shark fishing. *Current Biology* **27**, R97–R98 (2017).

21. Hosch, G. & Macfadyen, G. Killing Nemo: Three world regions fail to mainstream combatting of IUU fishing. *Marine Policy* **140**, 105073 (2022).

22. Eriksson, H. *et al.* Contagious exploitation of marine resources. *Frontiers in Ecology and the Environment* **13**, 435–440 (2015).

23. Scheffers, B. R., Oliveira, B. F., Lamb, I. & Edwards, D. P. Global wildlife trade across the tree of life. *Science* **366**, 71–76 (2019).

24. Senior, R. A., Oliveira, B. F., Dale, J. & Scheffers, B. R. Wildlife trade targets colorful birds and threatens the aesthetic value of nature. *Current Biology* **32**, 4299-4305.e4 (2022).

25. Chapman, D. D. *et al.* Ongoing trade of fins from critically endangered rays (wedgefish and

giant guitarfish) despite international regulations and a novel PCR test to detect rays among 'shark' fins. *Conservation Genetics* 1–11 (2025) doi:10.1007/s10592-025-01716-z.

26. Sherman, C. S. *et al.* Guitarfishes are plucked: Undermanaged in global fisheries despite declining populations and high volume of unreported international trade. *Marine Policy* **155**, 105753 (2023).
27. Chapman, D. D. *et al.* Ongoing trade of fins from critically endangered rays (wedgefish and giant guitarfish) despite international regulations and a novel PCR test to detect rays among 'shark' fins. *Conservation Genetics* 1–11 (2025) doi:10.1007/s10592-025-01716-z.
28. Rodenbiker, J. Shark Fin City: transitional marine wildlife economies in Global Hong Kong. *Urban Geography* **46**, 155–179 (2025).
29. Amepou, Y. *et al.* Maw money, maw problems: A lucrative fish maw fishery in Papua New Guinea highlights a global conservation issue driven by Chinese cultural demand. *Conservation Letters* **17**, e13006 (2024).
30. Bond, M. E. *et al.* Trade regulations drive improved global shark and ray management. *Marine Policy* **180**, 106733 (2025).
31. 't Sas-Rolfes, M., Challender, D. W. S., Hinsley, A., Veríssimo, D. & Milner-Gulland, E. J. Illegal Wildlife Trade: Scale, Processes, and Governance. *Annual Review of Environment and Resources* **44**, 201–228 (2019).
32. Cardeñosa, D. *et al.* International trade regulations take a limited bite out of the shark fin trade. *Science Advances* **11**, eadz2821 (2025).
33. Gephart, J. A. *et al.* Globalization of wild capture and farmed aquatic foods. *Nature Communications* **15**, 1–13 (2024).
34. Bertoli, S., Goujon, M. & Santoni, O. The CERDI-seadistance database. *Études et*

Documents **7**, (2016).

35. Fouquin, M. & Hugot, J. Two Centuries of Bilateral Trade and Gravity data: 1827-2014. *CEPII Working Paper* 39 (2016).
36. Conte, M., Cotterlaz, P. & Mayer, T. *The CEPII Gravity Database*. 46 (2023).
37. Natsika, N., Nord, M. & Lindberg, S. I. Measuring and Analyzing the Rule of Law: A Practical Guide. *V-Dem Institute Policy Brief* **41**, (2025).
38. Rousseau, Y. *et al.* A database of mapped global fishing activity 1950–2017. *Sci Data* **11**, 48 (2024).
39. Cardeñosa, D. *et al.* Small sharks, big problems: DNA analysis of small fins reveals trade regulation gaps and burgeoning trade in juvenile sharks. *Science Advances* **10**, eadq6214 (2024).
40. Vannuccini, S. Shark utilization, marketing and trade. *FAO Fisheries Technical Paper* **389**, 470 (1999).
41. Ebert, D. A., Fowler, S., Compagno, L. & Dando, M. *Sharks of the World: A Fully Illustrated Guide*. (Wild Nature Press, 2013).
42. Siders, Z. A., Caltabellotta, F. P., Loesser, K. B., Trotta, L. B. & Baiser, B. Using pictographs as traits to explore morphological diversity in sharks. *Ecology and Evolution* **13**, e9761 (2023).
43. Sternes, P. C., Schmitz, L. & Higham, T. E. The rise of pelagic sharks and adaptive evolution of pectoral fin morphology during the Cretaceous. *Current Biology* **34**, 2764-2772.e3 (2024).
44. Sadovy de Mitcheson, Y., To, A. W., Wong, N. W., Kwan, H. Y. & Bud, W. S. Emerging from the murk: threats, challenges and opportunities for the global swim bladder trade. *Rev*

Fish Biol Fisheries **29**, 809–835 (2019).

45. Thorson, J. T. *et al.* Identifying direct and indirect associations among traits by merging phylogenetic comparative methods and structural equation models. *Methods in Ecology and Evolution* **14**, 1259–1275 (2023).
46. McCune, A. R. & Carlson, R. L. Twenty ways to lose your bladder: common natural mutants in zebrafish and widespread convergence of swim bladder loss among teleost fishes. *Evolution & Development* **6**, 246–259 (2004).
47. Nakamura, G., Richter, A. & Soares, B. E. FishPhyloMaker: An R package to generate phylogenies for ray-finned fishes. *Ecological Informatics* **66**, 101481 (2021).
48. Stein, R. W. *et al.* Global priorities for conserving the evolutionary history of sharks, rays and chimaeras. *Nat Ecol Evol* **2**, 288–298 (2018).
49. Schliep, K. P. phangorn: phylogenetic analysis in R. *Bioinformatics* **27**, 592–593 (2011).
50. Ross, N., Sumner, M., Ooms, J. & Stevens, A. fasterize: Fast Polygon to Raster Conversion. (2024).
51. Fritz, S. A. & Purvis, A. Selectivity in Mammalian Extinction Risk and Threat Types: a New Measure of Phylogenetic Signal Strength in Binary Traits. *Conservation Biology* **24**, 1042–1051 (2010).
52. Pagel, M. Inferring the historical patterns of biological evolution. *Nature* **401**, 877–884 (1999).
53. Orme, D. *et al.* caper: Comparative Analyses of Phylogenetics and Evolution in R. (2023).
54. Revell, L. J. phytools 2.0: an updated R ecosystem for phylogenetic comparative methods (and other things). *PeerJ* **12**, e16505 (2024).
55. Ives, A. R. & Garland, T. Phylogenetic Logistic Regression for Binary Dependent

Variables. *Systematic Biology* **59**, 9–26 (2010).

56. Lechner, M. & Okasa, G. Random Forest estimation of the ordered choice model. *Empirical Economics* **68**, 1–106 (2024).
57. Lechner, M. & Okasa, G. orf: Ordered Random Forests. (2022).
58. Hornung, R. Ordinal Forests. *Journal of Classification* **37**, 4–17 (2019).
59. Gaulier, G. & Zignago, S. BACI: International Trade Database at the Product-Level (the 1994-2007 Version). *SSRN Journal* https://doi.org/10.2139/ssrn.1994500 (2010) doi:10.2139/ssrn.1994500.
60. Feitosa, L. M., Free, C. M., Bradley, D., Gephart, Jessica A. & Gaines, S. D. Trade and social governance drive serial exploitation of luxury seafood. Dryad https://doi.org/10.5061/dryad.n2z34tnc3 (2025).

Figures

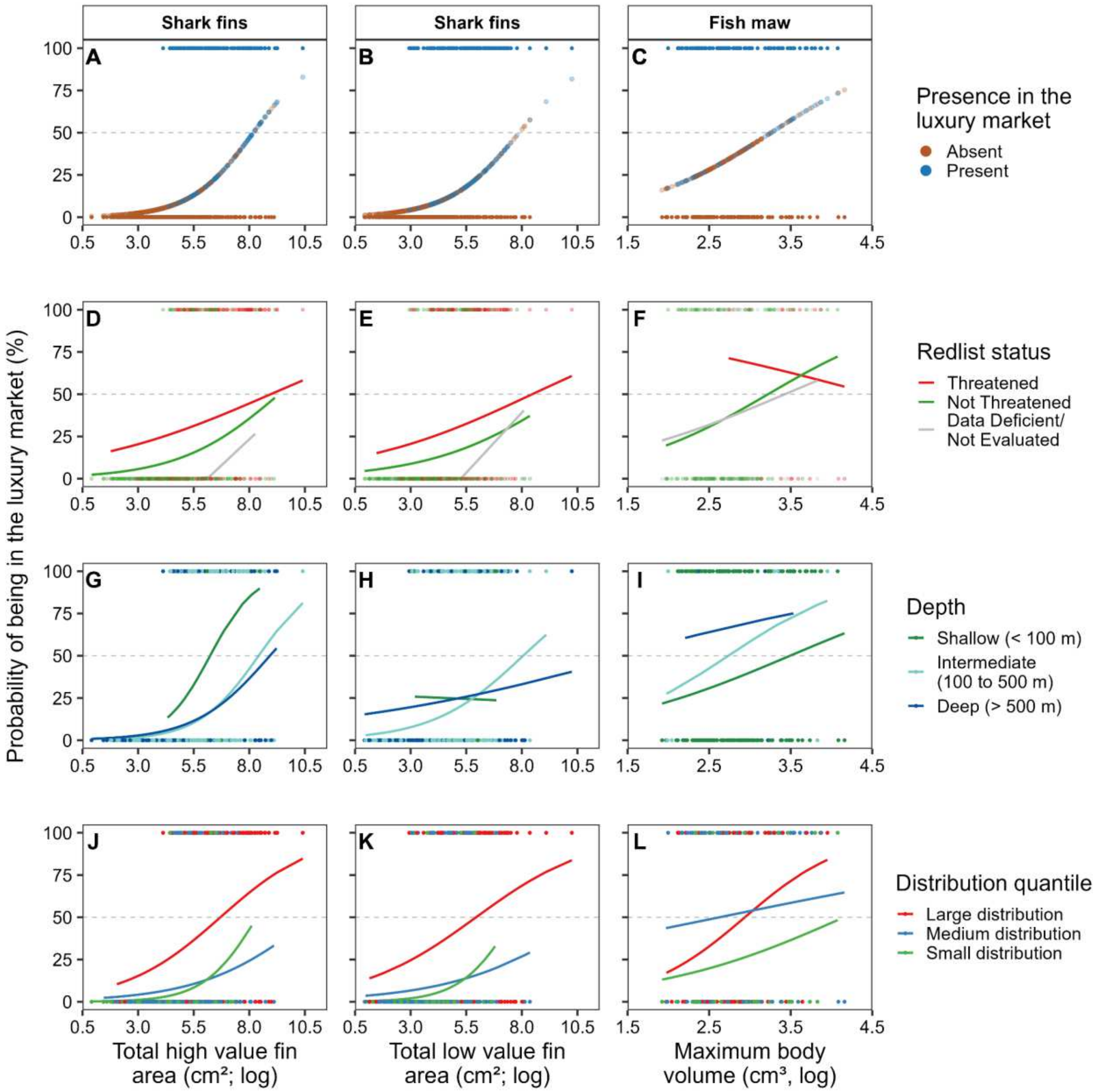

Figure 1: Species desirability increases probability of presence in the luxury market. Colored lines represent the different categorical predictors used to test multiple interactions for the phylogenetic logistic regression models. Panels A through C show the predicted probabilities of each species being in their respective luxury seafood markets as a function of desirability variables. Panels D through F demonstrate the interaction between desirability traits and species IUCN Red List categories (i.e, Least Concern (LC) - dark green, Near Threatened (NT) - light green, Vulnerable (VU) - light yellow, Endangered (EN) - orange, Critically Endangered (CR) - red, Data Deficient (DD) - gray, and Not Evaluated (NE) - black) and probability of being in the luxury seafood market. DD species have near zero probabilities of being in the shark fin market,

thus the trend line is behind points at the 0% probability in the y axis. Panels G through I show the interaction between desirability traits and species median depth intervals (Deep - dark blue, Intermediate - light green, Shallow - green) and probability of being in the luxury seafood market. Panels J though L show the interaction between desirability traits and the first, second, and third quantiles of species distribution ranges based on the number of countries where they occur and their probability of being in the luxury seafood market.

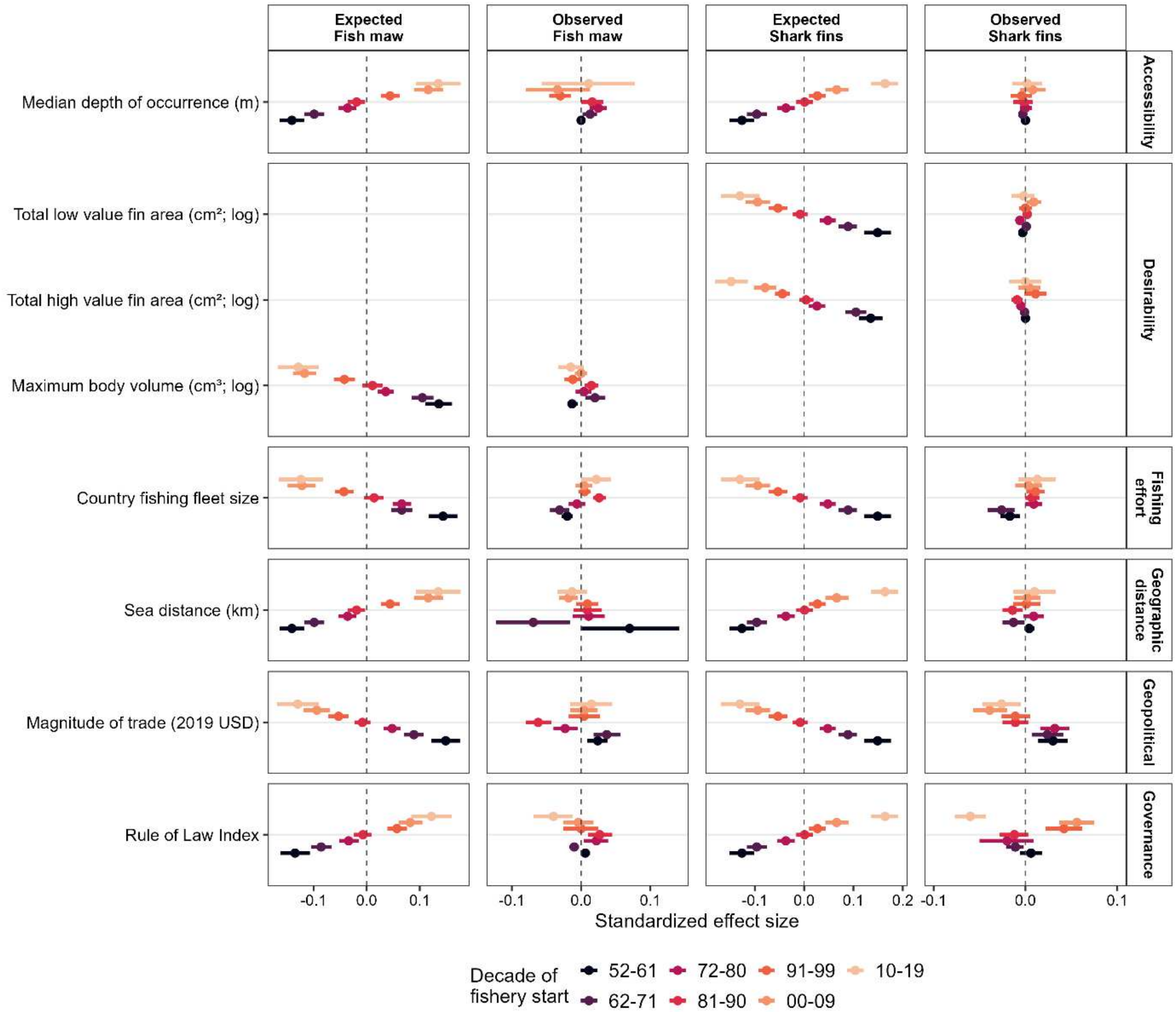

Figure 2. Trade and governance drive historical serial exploitation patterns across products. Mean (point) and 95% confidence intervals (horizontal error bars) for each predictor (y-axis) and ten-year interval for which a fishery for a given species in a given country started. Darker colors represent older fisheries and lighter colors those developed more recently. Expected patterns are based on models fitted with the fish maw and shark fin ordered datasets for China as the end-market and each predictor artificially arranged to match each hypothesis. Observed patterns are calculated across end-market countries through a weighted mean based on the share of the market each end-market country (China, Singapore, Vietnam) represents. Expected and observed panels are shown side by side for comparison.

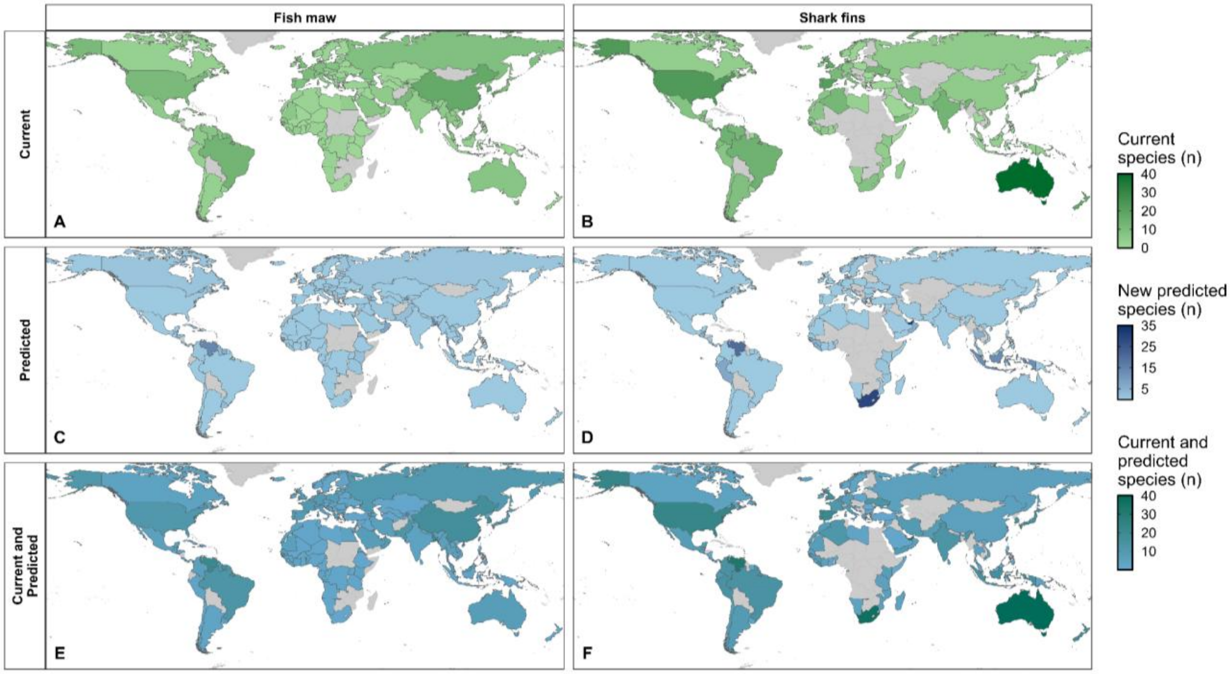

Figure 3. Current and future hotspots of exploitation for shark fins and fish maw. Panels A and B show countries colored by the number of species demanded in the fish maw and shark fin markets with reported landings in 2019. Panels C and D are colored by the number of species each country is predicted to exploit to supply the fish maw and shark fin markets in the future. Panels E and F show the number of species currently exploited plus the ones predicted to be exploited in each country by the ordered forest model for each product.

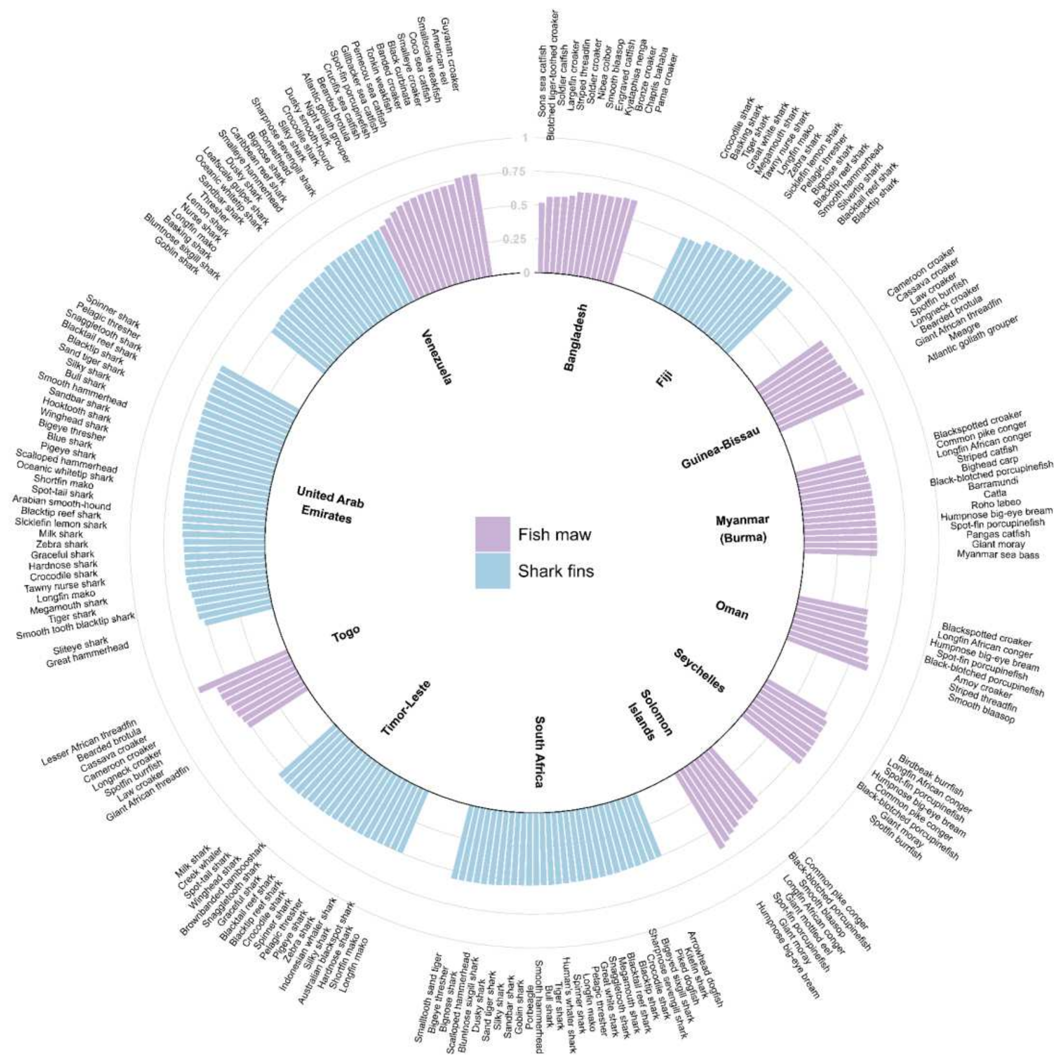

Figure 4. Predicted probabilities of exploitation for species within countries. Only the top five countries with the highest number of species predicted to become exploited for each product are shown. The entire pool of species and countries with probabilities of exploitation > 50% are shown on Supplementary Figures 8 and 9 for shark fins and fish maw, respectively.

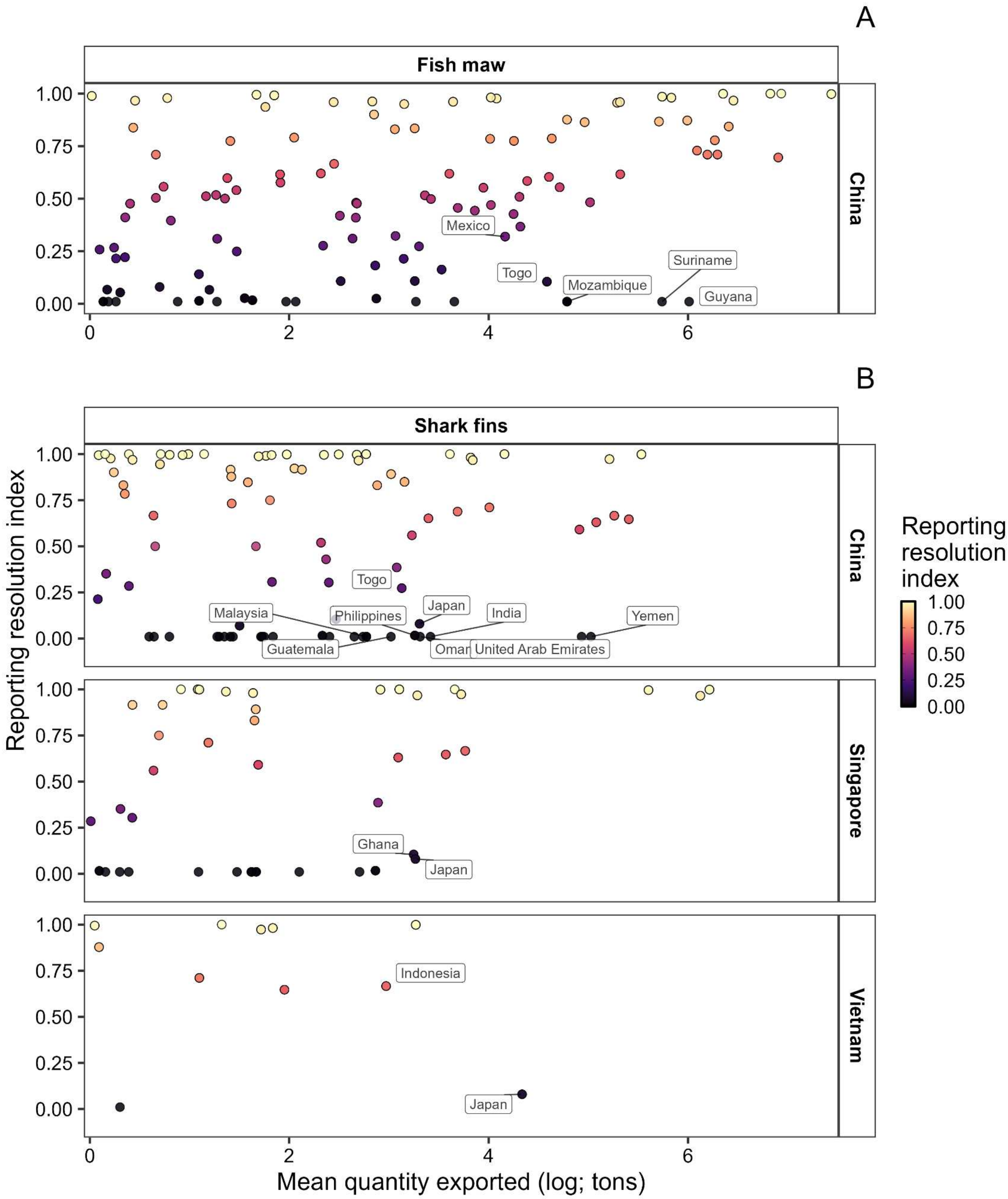

Figure 5. High exporters with landings reported at higher taxonomic levels are at elevated risk of IUU fishing. Values close to 1 (lighter points) represent countries reporting most of their landings at the species level, while values close to zero (darker points) represent countries reporting most of their landings at the class level. Labeled countries are those in the first tertile for the reporting resolution index and in the third tertile for the mean quantity exported of each product for each end-market country. These countries are considered to have a high probability

of exploiting multiple species but reporting landings only at higher taxonomic levels. High concern is statistically derived using a reporting resolution index, which measures what proportion of the fisheries landings reported is provided at each taxonomic level. Trade and reporting indices are shown for fish maw (A) and shark fins (B) based on each end-market country. Landings data are aggregated from the FAO fisheries database and bilateral trade data are aggregated from the BACI dataset, both spanning from 2012 to 2019.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Feitosaetalsupplementarymaterials.pdf