

Supplementary Information

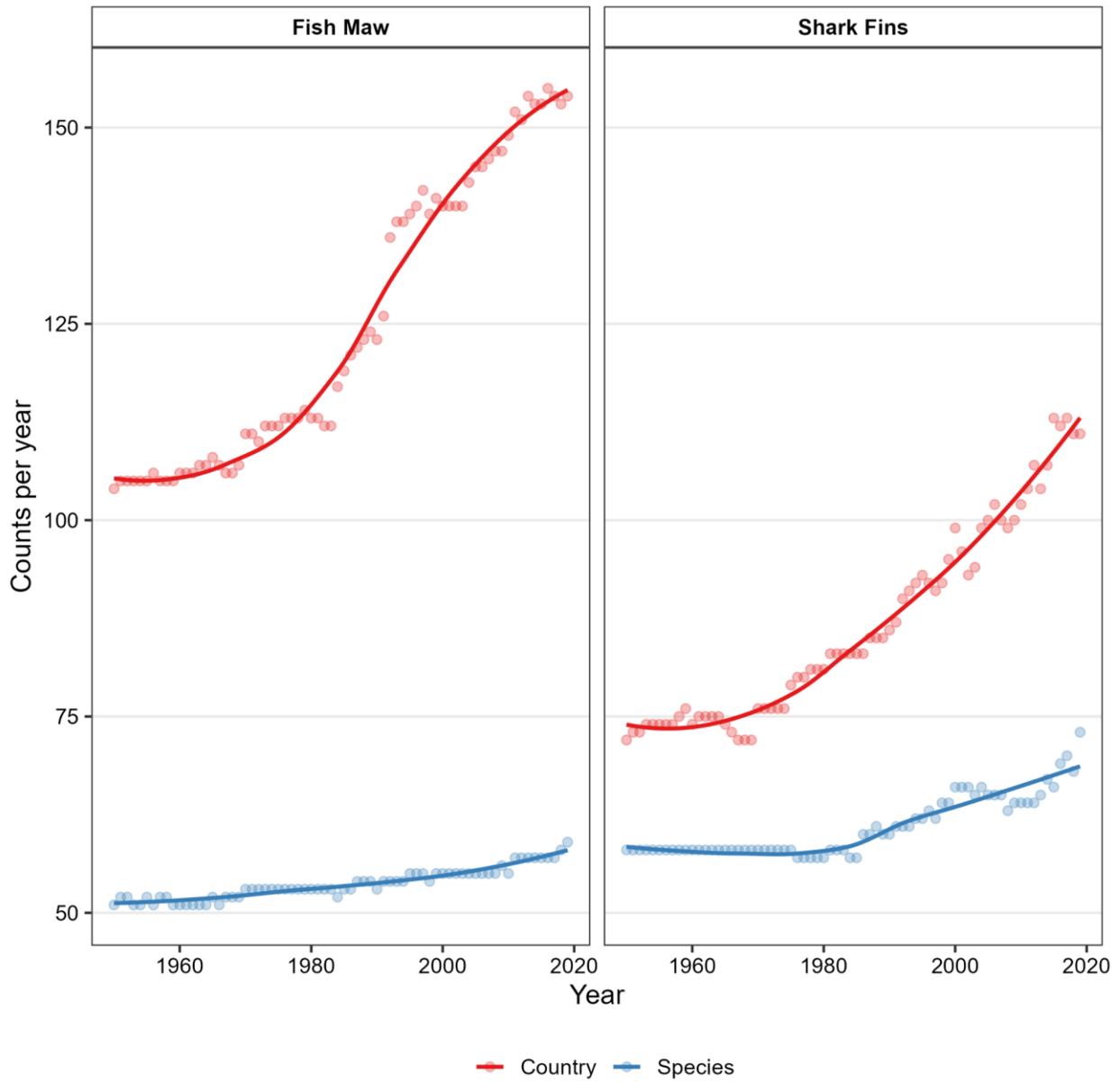
Trade and governance drive luxury seafood serial exploitation

Leonardo Manir Feitosa, Christopher M. Free, Darcy Bradley, Jessica A. Gephart, Steven D. Gaines

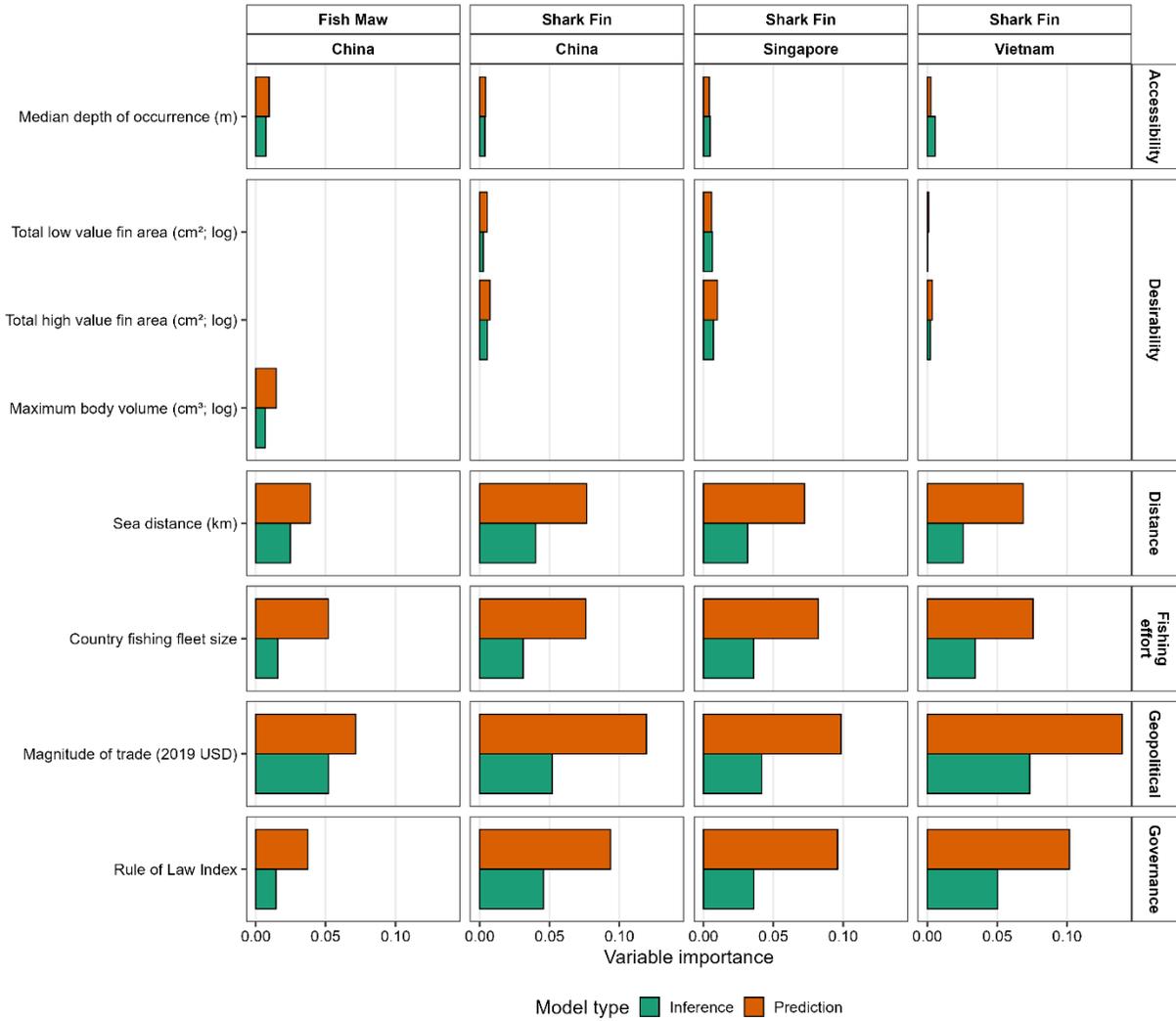
This PDF includes the following:

Figures S1-S12

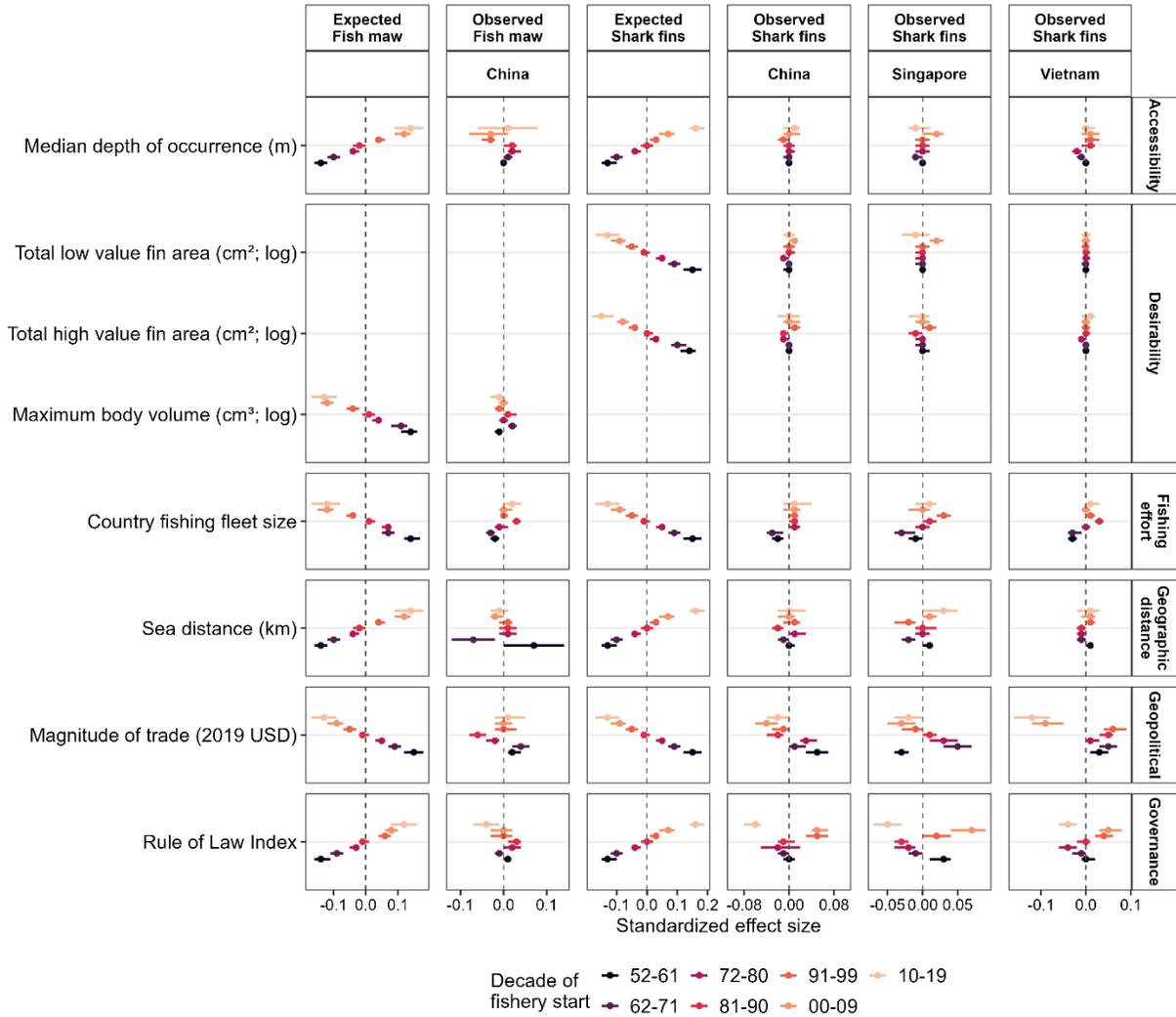
Tables S1-S5



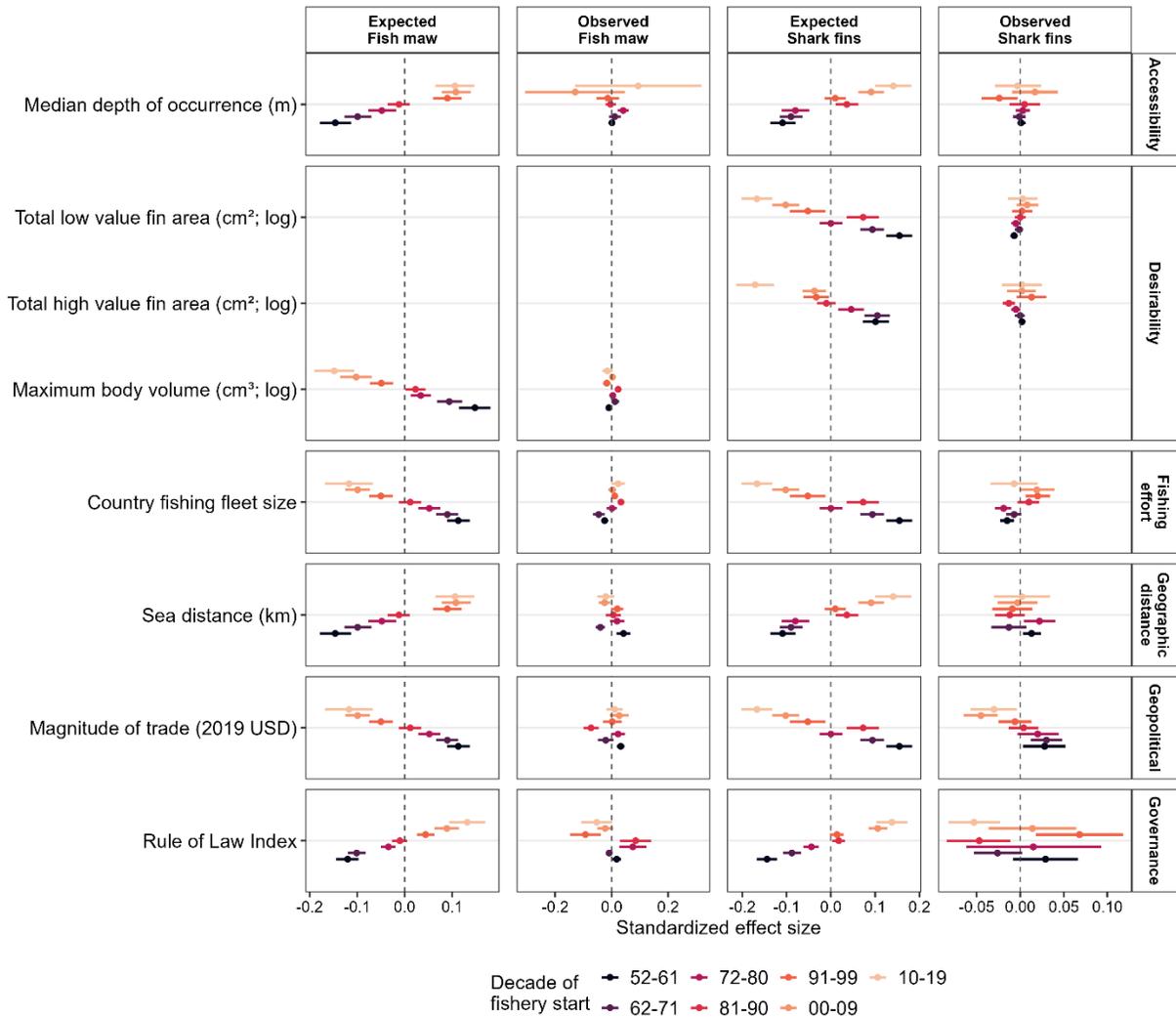
Supplementary Figure S1. Number of luxury species with landings reported by countries per year. These data aggregate both SAUP and FAO fisheries landings data.



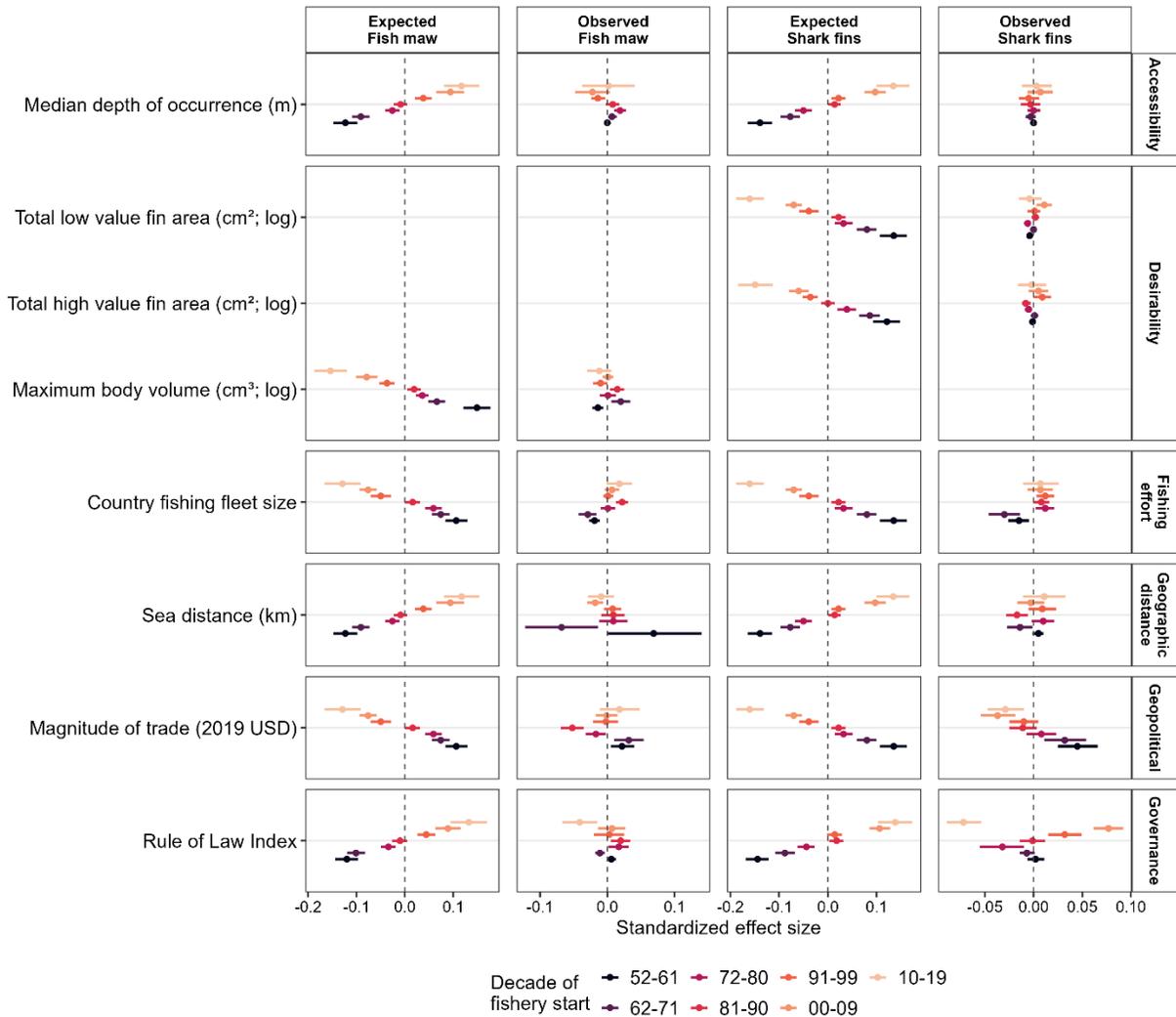
Supplementary Figure S2. Trade and governance variables are the most important predictors of serial exploitation. Bars represent the calculated variable importance for each predictor and end-market country model fit and are colored based on the model purpose (inference - green, or prediction - orange).



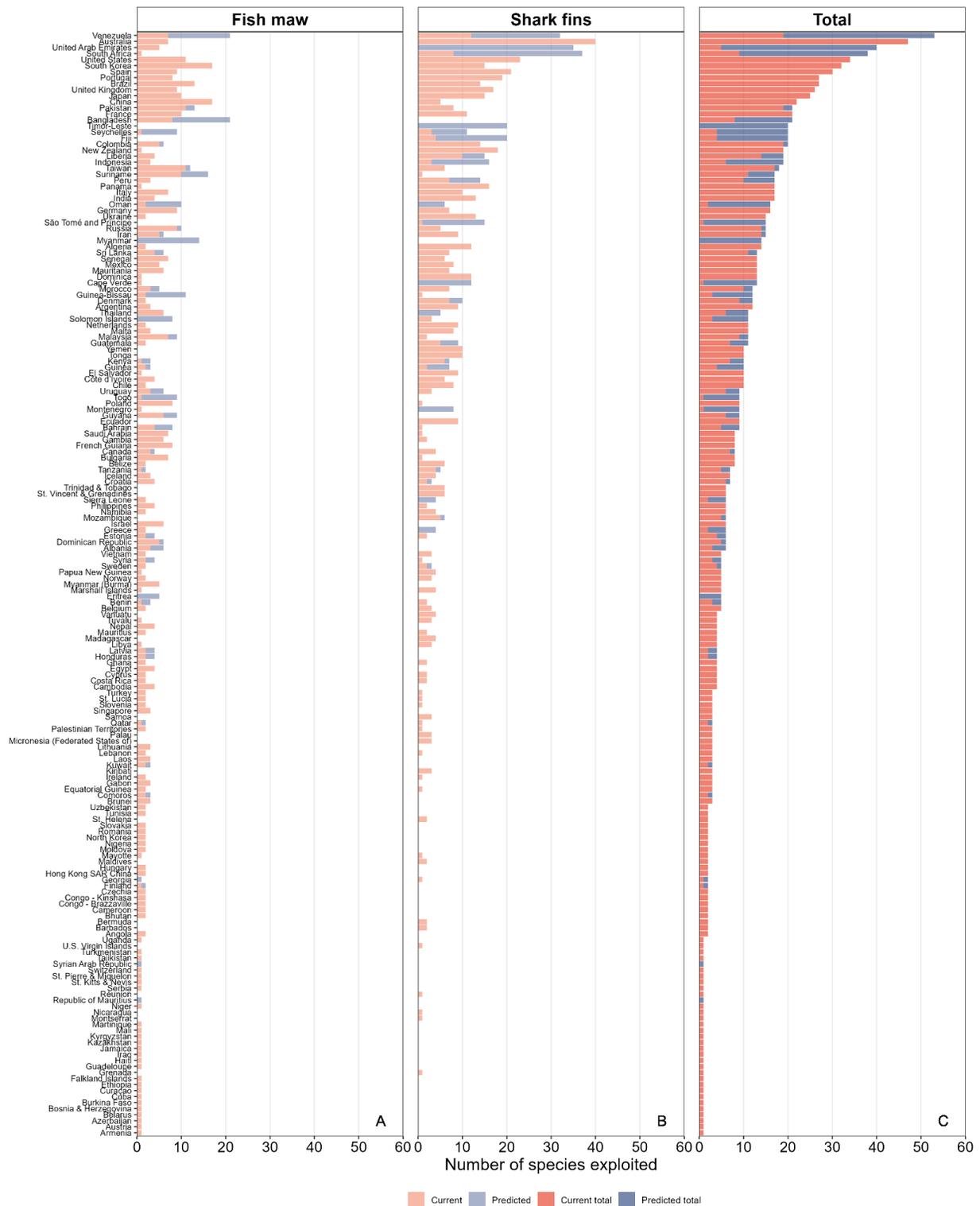
Supplementary Figure S3. Trade and governance drive historical serial exploitation patterns across products and end-market countries. Mean (point) and 95% confidence intervals (horizontal error bars) apply to each predictor (y-axis) for each ten-year interval for which a country reported the fishery for a given species. We compare the pattern expected (left panel) if each hypothesis were confirmed to the inference model output for each product (middle and right panels). Window parameter = 0.5.



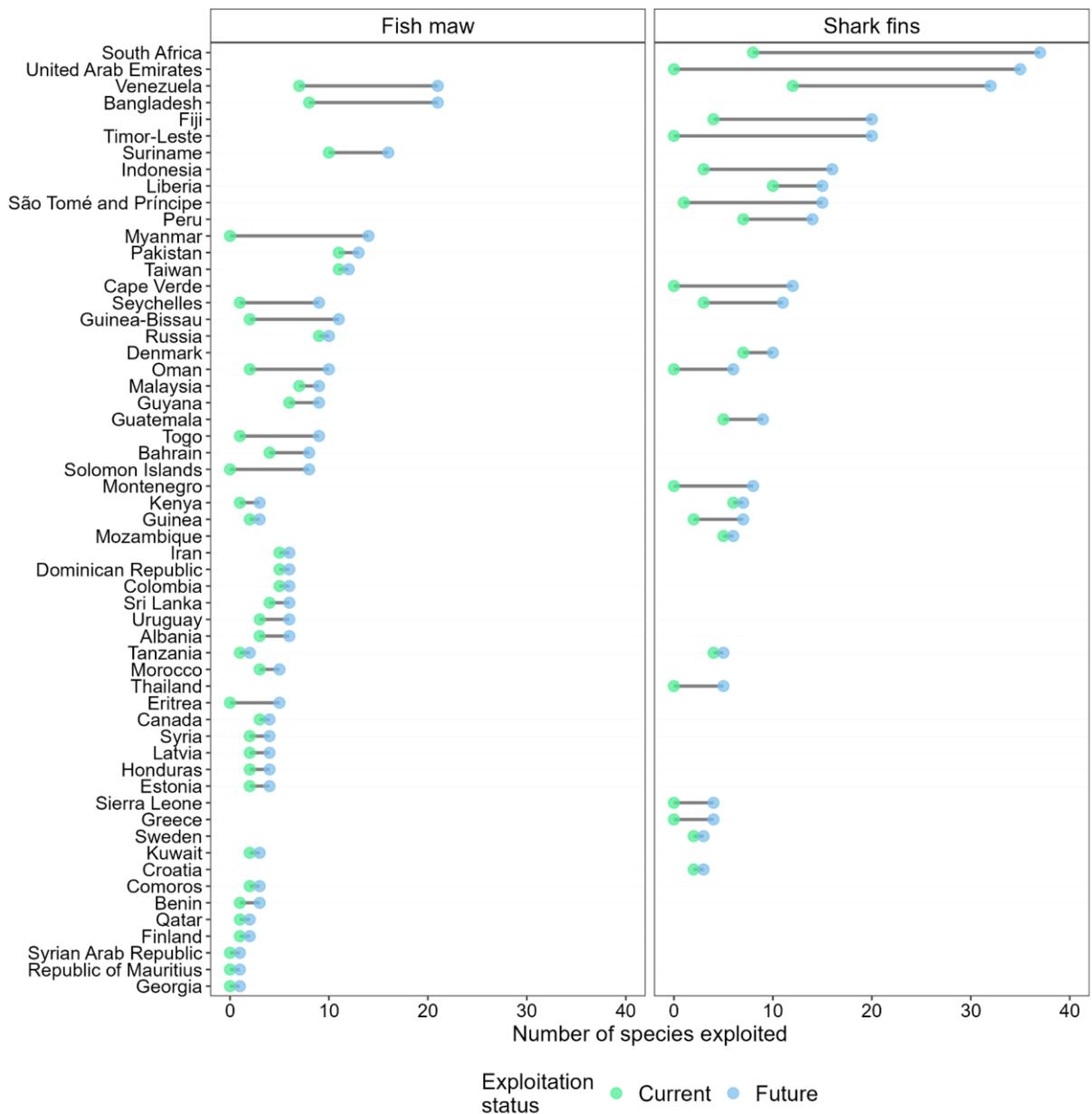
Supplementary Figure S4. Trade and governance drive historical serial exploitation patterns across products for window parameter = 0.1. Mean (point) and 95% confidence intervals (horizontal error bars) apply to each predictor (y-axis) for each ten-year interval for which a country reported the fishery for a given species. We compare the pattern expected (left panel) if each hypothesis were confirmed to the inference model output for each product (middle and right panels).



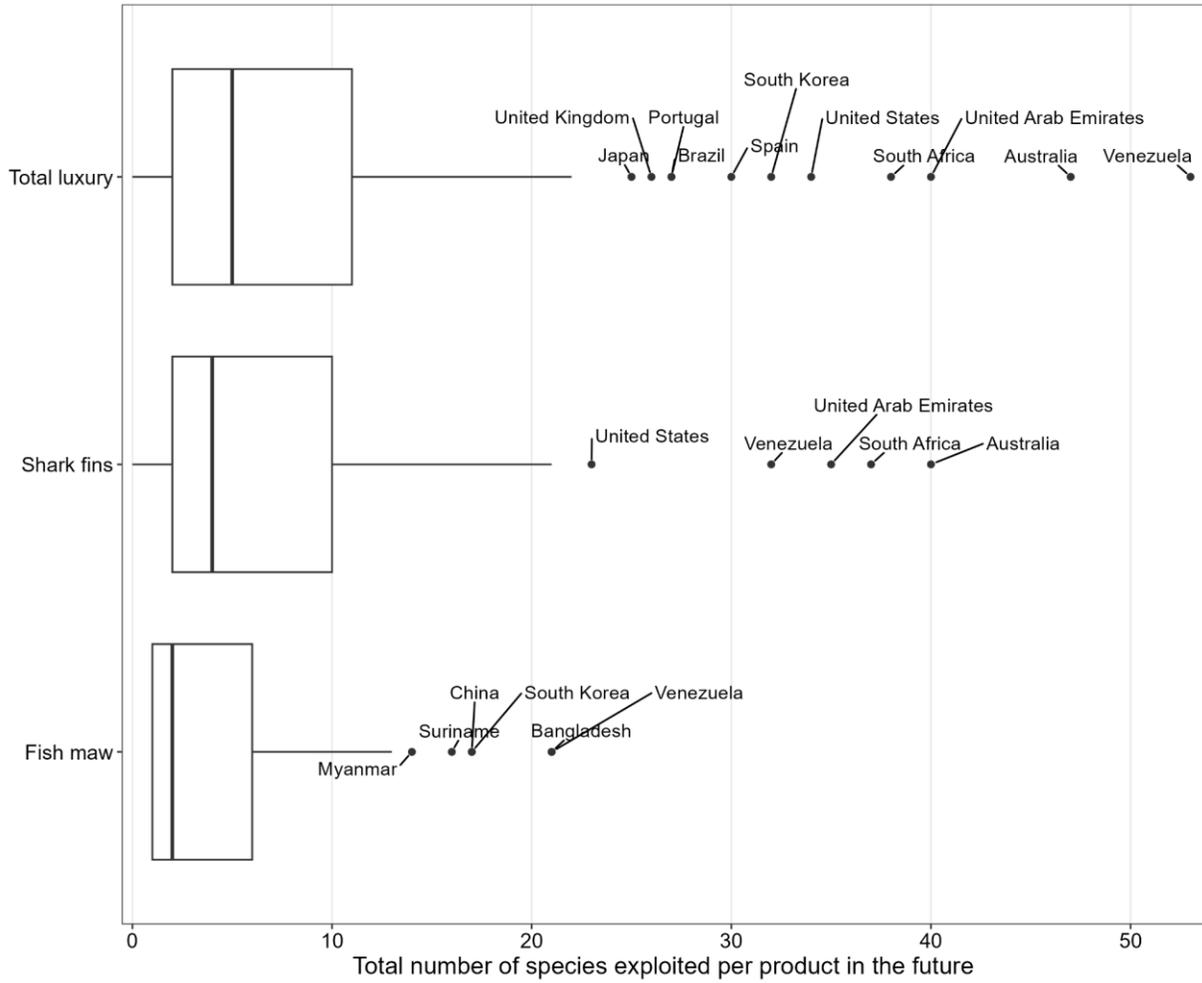
Supplementary Figure S5. Trade and governance drive historical serial exploitation patterns across products for window parameter = 1. Mean (point) and 95% confidence intervals (horizontal error bars) apply to each predictor (y-axis) for each ten-year interval for which a country reported the fishery for a given species. We compare the pattern expected (left panel) if each hypothesis were confirmed to the inference model output for each product (middle and right panels).



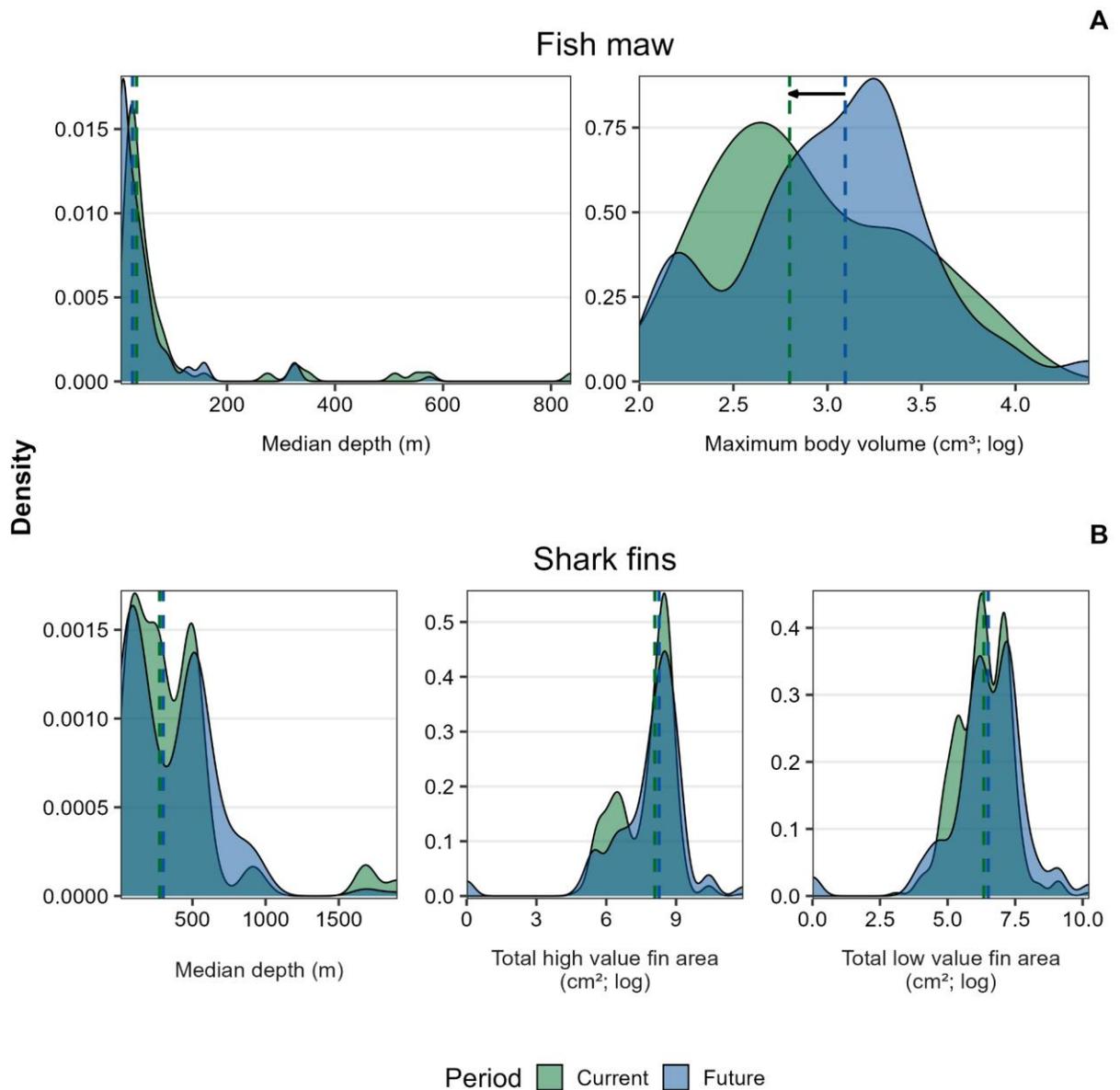
Supplementary Figure S6. Total and product-specific count of species currently and predicted to be exploited in the future. We show the current and predicted number of species exploited per country for fish maw (A), shark fins (B), and the sum of both categories for all products (C).



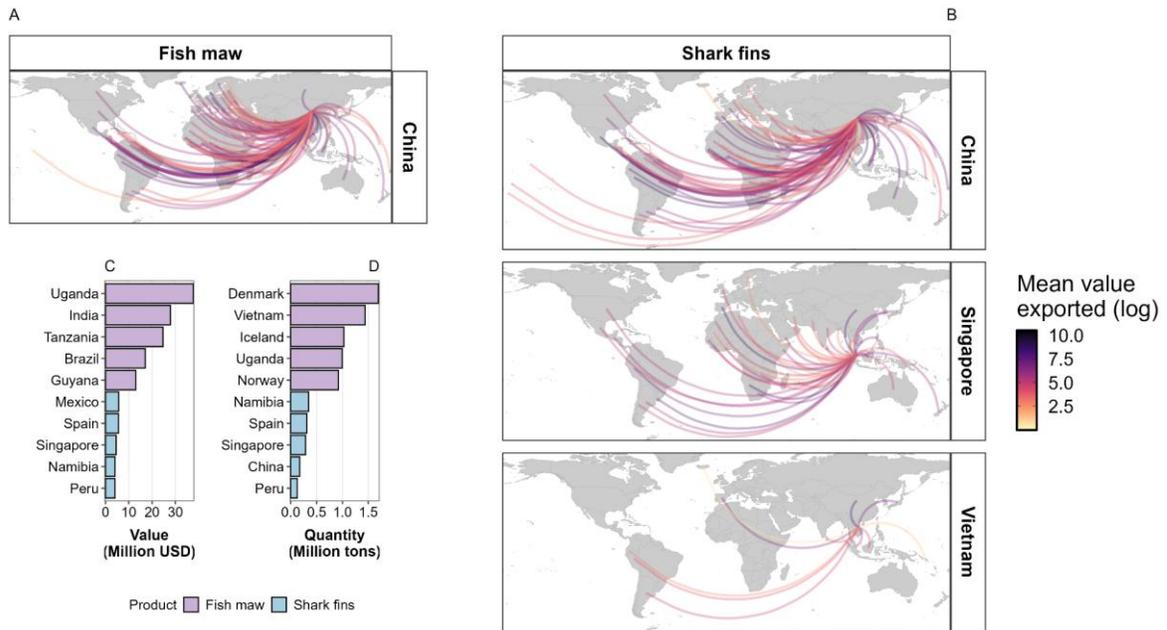
Supplementary Figure S7: Predicted changes in the number of species exploited per country and product. The number of species exploited in the future includes the ones currently reported and those predicted by the ordered forest models. Only countries with non-zero species predicted to be exploited are included.



Supplementary Figure S8. Future hotspots of exploitation for luxury seafood products. Labeled countries are above the 95% quantile and are thus predicted to become outliers in the number of species exploited for luxury seafood consumption.



Supplementary Figure S11. Distribution shifts in species' biological features between species currently exploited and those predicted to enter markets for each product. Both density distributions only encompass species currently exploited or those with > 50% chance of being exploited in the future for fish maw (A) or shark fins (B). Vertical lines represent median values for species currently and those predicted to be exploited. Horizontal arrows show the change in the median between current and predicted species pools.



Supplementary Figure S12. Mean bilateral trade for each product and end-market country. We show mean global trade flows in log-scale current USD for fish maw with China as the end-market country (A) and for shark fins with China, Singapore, and Vietnam as the end-market countries (B). The top five exporters globally are shown by value (million USD) (C) and quantity (million tons) (D).

Supplementary Table S1: Species-level landings reporting by country in 1950 and 2019 for shark fins and fish maw. The number of species reported for both years is the number of species known to be exploited for luxury in each market and reported in country-specific landings from the combined SAUP and FAO datasets. The difference in the number of species landed in each country is the difference between 2019 and 1950. The percent change in the number of species exploited is calculated as the ratio between the number of species landed in 2019 and those in 1950. The table is arranged in descending order of the difference in number of species landed for each product.

Product	Country	Species in 1950 (n)	Species in 2019 (n)	Difference in species (n)	Change in number of species (%)
Fish maw	China	6	17	11	183.333
	South Korea	7	17	10	142.857
	Poland	1	8	7	700
	Russia	2	9	7	350
	Bulgaria	1	7	6	600
	Italy	1	7	6	600
	Japan	4	10	6	150
	Venezuela	1	7	6	600
	France	5	10	5	100
	Germany	4	9	5	125
	Taiwan	6	11	5	83.333
	United Kingdom	4	9	5	125
	Bangladesh	4	8	4	100

Dominican Republic	1	5	4	400
Israel	2	6	4	200
Malaysia	3	7	4	133.333
Myanmar (Burma)	1	5	4	400
Saudi Arabia	3	7	4	133.333
United Arab Emirates	1	5	4	400
Bahrain	1	4	3	300
Côte d'Ivoire	1	4	3	300
Gambia	3	6	3	100
Liberia	1	4	3	300
Mauritania	3	6	3	100
Mexico	2	5	3	150
Pakistan	8	11	3	37.5
Senegal	4	7	3	75
Sri Lanka	1	4	3	300
Albania	1	3	2	200
Argentina	1	3	2	200
Australia	5	7	2	40

Egypt	2	4	2	100
Gabon	1	3	2	200
India	2	4	2	100
Lithuania	1	3	2	200
Malta	1	3	2	200
Peru	1	3	2	200
Portugal	6	8	2	33.333
Singapore	1	3	2	200
Thailand	4	6	2	50
Algeria	1	2	1	100
Angola	1	2	1	100
Brazil	12	13	1	8.333
Canada	2	3	1	50
Congo - Brazzaville	1	2	1	100
Congo - Kinshasa	1	2	1	100
Estonia	1	2	1	100
Ghana	1	2	1	100
Guatemala	1	2	1	100

Guinea	1	2	1	100
Guinea-Bissau	1	2	1	100
Honduras	1	2	1	100
Iceland	2	3	1	50
Indonesia	2	3	1	50
Iran	4	5	1	25
Latvia	1	2	1	100
Morocco	2	3	1	50
Nigeria	1	2	1	100
Oman	1	2	1	100
Philippines	3	4	1	33.333
Sierra Leone	1	2	1	100
Slovenia	1	2	1	100
Syria	1	2	1	100
Tunisia	1	2	1	100
Uruguay	2	3	1	50
Belgium	2	2	0	0
Belize	2	2	0	0

Benin	1	1	0	0
Bosnia & Herzegovina	1	1	0	0
Cape Verde	1	1	0	0
Chile	2	2	0	0
Costa Rica	2	2	0	0
Cuba	1	1	0	0
Denmark	2	2	0	0
Finland	1	1	0	0
Guyana	6	6	0	0
Hungary	2	2	0	0
Ireland	2	2	0	0
Jamaica	1	1	0	0
Kuwait	2	2	0	0
Libya	1	1	0	0
Mali	1	1	0	0
Marshall Islands	1	1	0	0
Montenegro	1	1	0	0
Namibia	2	2	0	0

Netherlands	2	2	0	0
New Zealand	1	1	0	0
North Korea	2	2	0	0
Norway	2	2	0	0
Papua New Guinea	1	1	0	0
Romania	2	2	0	0
South Africa	1	1	0	0
Spain	9	9	0	0
St. Pierre & Miquelon	1	1	0	0
Suriname	10	10	0	0
Sweden	2	2	0	0
Turkey	2	2	0	0
Tuvalu	1	1	0	0
Uganda	1	1	0	0
El Salvador	2	1	-1	-50
Hong Kong SAR China	3	2	-1	-33.333
Togo	2	1	-1	-50
United States	12	11	-1	-8.333

Greece	4	2	-2	-50
Armenia		1		
Austria		1		
Azerbaijan		1		
Belarus		1		
Bhutan		2		
Brunei		3		
Burkina Faso		1		
Cambodia		4		
Cameroon		2		
Colombia		5		
Comoros		2		
Croatia		4		
Curaçao		1		
Cyprus		2		
Czechia		2		
Dominica		1		
Equatorial Guinea		2		

Ethiopia	1
Falkland Islands	1
French Guiana	8
Guadeloupe	1
Haiti	1
Iraq	1
Kazakhstan	1
Kenya	1
Kyrgyzstan	1
Laos	3
Lebanon	2
Martinique	1
Mauritius	2
Mayotte	1
Moldova	2
Nepal	4
Niger	1
Palestinian Territories	2

Panama	1
Qatar	1
Serbia	1
Seychelles	1
Slovakia	2
St. Kitts & Nevis	1
St. Lucia	2
Switzerland	1
Tajikistan	1
Tanzania	1
Turkmenistan	1
Ukraine	2
Uzbekistan	2
Vietnam	2

Shark fins	Australia	21	40	19	90.476
	New Zealand	3	18	15	500
	Panama	2	16	14	700
	South Korea	3	15	12	400

Ukraine	1	13	12	1200
Venezuela	1	12	11	1100
Japan	5	15	10	200
Liberia	1	10	9	900
Iran	2	9	7	350
Denmark	1	7	6	600
Mexico	2	8	6	300
Netherlands	3	9	6	200
Italy	5	10	5	100
South Africa	3	8	5	166.667
Spain	16	21	5	31.25
Sri Lanka	2	7	5	250
Taiwan	1	6	5	500
Trinidad & Tobago	1	6	5	500
United Kingdom	12	17	5	41.667
Algeria	8	12	4	50
Chile	4	8	4	100
Mauritania	3	7	4	133.333

Pakistan	4	8	4	100
Portugal	15	19	4	26.667
Russia	1	5	4	400
Argentina	6	9	3	50
France	8	11	3	37.5
Guatemala	2	5	3	150
Malta	5	8	3	60
Tonga	7	10	3	42.857
Belgium	1	3	2	200
China	3	5	2	66.667
Germany	5	7	2	40
Indonesia	1	3	2	200
Madagascar	2	4	2	100
Namibia	2	4	2	100
Libya	2	3	1	50
Mozambique	4	5	1	25
Peru	6	7	1	16.667
Philippines	1	2	1	100

St. Helena	1	2	1	100
Sweden	1	2	1	100
Yemen	9	10	1	11.111
Belize	6	6	0	0
Brazil	14	14	0	0
Bulgaria	1	1	0	0
Costa Rica	2	2	0	0
El Salvador	9	9	0	0
Georgia	1	1	0	0
Guinea	2	2	0	0
Malaysia	2	2	0	0
Montserrat	1	1	0	0
Norway	3	3	0	0
Palestinian Territories	1	1	0	0
Slovenia	1	1	0	0
St. Lucia	1	1	0	0
Turkey	1	1	0	0
India	14	13	-1	-7.143
Ireland	2	1	-1	-50

Syria	2	1	-1	-50
Uruguay	4	3	-1	-25
Seychelles	5	3	-2	-40
Solomon Islands	6	3	-3	-50
United States	28	23	-5	-17.857
Maldives	10	2	-8	-80
Cayman Islands	1			
Greece	1			
Romania	1			
Sierra Leone	4			
Somalia	3			
St. Pierre & Miquelon	2			
Bahrain		1		
Barbados		2		
Benin		2		
Bermuda		2		
Canada		4		
Colombia		14		

Croatia	2
Cyprus	2
Côte d'Ivoire	6
Dominica	12
Ecuador	9
Equatorial Guinea	1
Estonia	2
Fiji	4
Gambia	2
Ghana	2
Grenada	1
Guinea-Bissau	1
Iceland	4
Kenya	6
Kiribati	3
Lebanon	1
Marshall Islands	4
Mauritius	2

Mayotte	1
Micronesia (Federated States of)	3
Morocco	7
Nicaragua	1
Palau	3
Papua New Guinea	4
Poland	1
Qatar	1
Reunion	1
Samoa	3
Saudi Arabia	1
Senegal	6
St. Vincent & Grenadines	6
Suriname	1
São Tomé and Príncipe	1
Tanzania	4
Tuvalu	3
U.S. Virgin Islands	1

Vanuatu	4
---------	---

Vietnam	3
---------	---

Supplementary Table S2. List of countries predicted to enter the luxury seafood market for each product.

Product	Country
Fish maw	Eritrea
	Georgia
	Solomon Islands
Shark fins	United Arab Emirates
	Cape Verde
	Djibouti
	Kuwait
	Montenegro
	Oman
	Thailand
	Timor-Leste

Supplementary Table S3: Current and predicted number of species exploited by product in each country and their percent changes. The number of current species is reported as the number of species known to be exploited for luxury in each market and reported in country-specific landings from the combined SAUP and FAO datasets in 2019. The number of future species exploited is a sum of the number of species currently exploited with the ones predicted to be exploited based on the Ordered Forest models. The added species column shows the number of additional species expected to be exploited by each country based on the Ordered Forest model predictions. The percent change in the number of species exploited is calculated as the ratio between the number of future and current species exploited. The table is arranged in descending order of the number of future species exploited for each product.

Product	Country	Current species (n)	Future species (n)	Added species (n)	Change in species n (%)
Shark fins	Australia	40	40	0	0
	South Africa	8	37	29	362
	United Arab Emirates	0	35	35	Inf
	Venezuela	12	32	20	167
	United States	23	23	0	0
	Spain	21	21	0	0
	Fiji	4	20	16	400
	Timor-Leste	0	20	20	Inf
	Portugal	19	19	0	0
	New Zealand	18	18	0	0
	United Kingdom	17	17	0	0
	Indonesia	3	16	13	433
	Panama	16	16	0	0
	Japan	15	15	0	0
	Liberia	10	15	5	50

South Korea	15	15	0	0
São Tomé and Príncipe	1	15	14	1400
Brazil	14	14	0	0
Colombia	14	14	0	0
Peru	7	14	7	100
India	13	13	0	0
Ukraine	13	13	0	0
Algeria	12	12	0	0
Cape Verde	0	12	12	Inf
Dominica	12	12	0	0
France	11	11	0	0
Seychelles	3	11	8	267
Denmark	7	10	3	43
Italy	10	10	0	0
Tonga	10	10	0	0
Yemen	10	10	0	0
Argentina	9	9	0	0
Ecuador	9	9	0	0
El Salvador	9	9	0	0
Guatemala	5	9	4	80
Iran	9	9	0	0
Netherlands	9	9	0	0
Chile	8	8	0	0
Malta	8	8	0	0
Mexico	8	8	0	0

Montenegro	0	8	8	Inf
Pakistan	8	8	0	0
Germany	7	7	0	0
Guinea	2	7	5	250
Kenya	6	7	1	17
Mauritania	7	7	0	0
Morocco	7	7	0	0
Sri Lanka	7	7	0	0
Belize	6	6	0	0
Côte d'Ivoire	6	6	0	0
Mozambique	5	6	1	20
Oman	0	6	6	Inf
Senegal	6	6	0	0
St. Vincent & Grenadines	6	6	0	0
Taiwan	6	6	0	0
Trinidad & Tobago	6	6	0	0
China	5	5	0	0
Russia	5	5	0	0
Tanzania	4	5	1	25
Thailand	0	5	5	Inf
Canada	4	4	0	0
Greece	0	4	4	Inf
Iceland	4	4	0	0
Madagascar	4	4	0	0

Marshall Islands	4	4	0	0
Namibia	4	4	0	0
Papua New Guinea	4	4	0	0
Sierra Leone	0	4	4	Inf
Vanuatu	4	4	0	0
Belgium	3	3	0	0
Croatia	2	3	1	50
Kiribati	3	3	0	0
Libya	3	3	0	0
Federated States of Micronesia	3	3	0	0
Norway	3	3	0	0
Palau	3	3	0	0
Samoa	3	3	0	0
Solomon Islands	3	3	0	0
Sweden	2	3	1	50
Tuvalu	3	3	0	0
Uruguay	3	3	0	0
Vietnam	3	3	0	0
Barbados	2	2	0	0
Benin	2	2	0	0
Bermuda	2	2	0	0
Costa Rica	2	2	0	0
Cyprus	2	2	0	0
Estonia	2	2	0	0

Gambia	2	2	0	0
Ghana	2	2	0	0
Malaysia	2	2	0	0
Maldives	2	2	0	0
Mauritius	2	2	0	0
Philippines	2	2	0	0
St. Helena	2	2	0	0
Bahrain	1	1	0	0
Bulgaria	1	1	0	0
Equatorial Guinea	1	1	0	0
Georgia	1	1	0	0
Grenada	1	1	0	0
Guinea-Bissau	1	1	0	0
Ireland	1	1	0	0
Lebanon	1	1	0	0
Mayotte	1	1	0	0
Montserrat	1	1	0	0
Nicaragua	1	1	0	0
Palestinian Territories	1	1	0	0
Poland	1	1	0	0
Qatar	1	1	0	0
Réunion	1	1	0	0
Saudi Arabia	1	1	0	0
Slovenia	1	1	0	0
St. Lucia	1	1	0	0

	Suriname	1	1	0	0
	Syria	1	1	0	0
	Turkey	1	1	0	0
	U.S. Virgin Islands	1	1	0	0
<hr/>					
Fish maw	Bangladesh	8	21	13	162
	Venezuela	7	21	14	200
	China	17	17	0	0
	South Korea	17	17	0	0
	Suriname	10	16	6	60
	Myanmar	0	14	14	Inf
	Brazil	13	13	0	0
	Pakistan	11	13	2	18
	Taiwan	11	12	1	9
	Guinea-Bissau	2	11	9	450
	United States	11	11	0	0
	France	10	10	0	0
	Japan	10	10	0	0
	Oman	2	10	8	400
	Russia	9	10	1	11
	Germany	9	9	0	0

Guyana	6	9	3	50
Malaysia	7	9	2	29
Seychelles	1	9	8	800
Spain	9	9	0	0
Togo	1	9	8	800
United Kingdom	9	9	0	0
Bahrain	4	8	4	100
French Guiana	8	8	0	0
Poland	8	8	0	0
Portugal	8	8	0	0
Solomon Islands	0	8	8	Inf
Australia	7	7	0	0
Bulgaria	7	7	0	0
Italy	7	7	0	0
Saudi Arabia	7	7	0	0
Senegal	7	7	0	0
Albania	3	6	3	100
Colombia	5	6	1	20
Dominican Republic	5	6	1	20
Gambia	6	6	0	0

Iran	5	6	1	20
Israel	6	6	0	0
Mauritania	6	6	0	0
Sri Lanka	4	6	2	50
Thailand	6	6	0	0
Uruguay	3	6	3	100
Eritrea	0	5	5	Inf
Mexico	5	5	0	0
Morocco	3	5	2	67
Myanmar (Burma)	5	5	0	0
United Arab Emirates	5	5	0	0
Cambodia	4	4	0	0
Canada	3	4	1	33
Croatia	4	4	0	0
Côte d'Ivoire	4	4	0	0
Egypt	4	4	0	0
Estonia	2	4	2	100
Honduras	2	4	2	100
India	4	4	0	0
Latvia	2	4	2	100

Liberia	4	4	0	0
Nepal	4	4	0	0
Philippines	4	4	0	0
Syria	2	4	2	100
Argentina	3	3	0	0
Benin	1	3	2	200
Brunei	3	3	0	0
Comoros	2	3	1	50
Gabon	3	3	0	0
Guinea	2	3	1	50
Iceland	3	3	0	0
Indonesia	3	3	0	0
Kenya	1	3	2	200
Kuwait	2	3	1	50
Laos	3	3	0	0
Lithuania	3	3	0	0
Malta	3	3	0	0
Peru	3	3	0	0
Singapore	3	3	0	0
Algeria	2	2	0	0

Angola	2	2	0	0
Belgium	2	2	0	0
Belize	2	2	0	0
Bhutan	2	2	0	0
Cameroon	2	2	0	0
Chile	2	2	0	0
Congo - Brazzaville	2	2	0	0
Congo - Kinshasa	2	2	0	0
Costa Rica	2	2	0	0
Cyprus	2	2	0	0
Czechia	2	2	0	0
Denmark	2	2	0	0
Equatorial Guinea	2	2	0	0
Finland	1	2	1	100
Ghana	2	2	0	0
Greece	2	2	0	0
Guatemala	2	2	0	0
Hong Kong SAR China	2	2	0	0
Hungary	2	2	0	0
Ireland	2	2	0	0

Lebanon	2	2	0	0
Mauritius	2	2	0	0
Moldova	2	2	0	0
Namibia	2	2	0	0
Netherlands	2	2	0	0
Nigeria	2	2	0	0
North Korea	2	2	0	0
Norway	2	2	0	0
Palestinian Territories	2	2	0	0
Qatar	1	2	1	100
Romania	2	2	0	0
Sierra Leone	2	2	0	0
Slovakia	2	2	0	0
Slovenia	2	2	0	0
St. Lucia	2	2	0	0
Sweden	2	2	0	0
Tanzania	1	2	1	100
Tunisia	2	2	0	0
Turkey	2	2	0	0
Ukraine	2	2	0	0

Uzbekistan	2	2	0	0
Vietnam	2	2	0	0
Armenia	1	1	0	0
Austria	1	1	0	0
Azerbaijan	1	1	0	0
Belarus	1	1	0	0
Bosnia & Herzegovina	1	1	0	0
Burkina Faso	1	1	0	0
Cape Verde	1	1	0	0
Cuba	1	1	0	0
Curaçao	1	1	0	0
Dominica	1	1	0	0
El Salvador	1	1	0	0
Ethiopia	1	1	0	0
Falkland Islands	1	1	0	0
Georgia	0	1	1	Inf
Guadeloupe	1	1	0	0
Haiti	1	1	0	0
Iraq	1	1	0	0
Jamaica	1	1	0	0

Kazakhstan	1	1	0	0
Kyrgyzstan	1	1	0	0
Libya	1	1	0	0
Mali	1	1	0	0
Marshall Islands	1	1	0	0
Martinique	1	1	0	0
Mayotte	1	1	0	0
Montenegro	1	1	0	0
New Zealand	1	1	0	0
Niger	1	1	0	0
Panama	1	1	0	0
Papua New Guinea	1	1	0	0
Republic of Mauritius	0	1	1	Inf
Serbia	1	1	0	0
South Africa	1	1	0	0
St. Kitts & Nevis	1	1	0	0
St. Pierre & Miquelon	1	1	0	0
Switzerland	1	1	0	0
Syrian Arab Republic	0	1	1	Inf
Tajikistan	1	1	0	0

Turkmenistan	1	1	0	0
Tuvalu	1	1	0	0
Uganda	1	1	0	0

Supplementary Table S4: Phylogenetic logistic regression model formulas for each research question and product.

Research question	Model formula
Does total high value fin area predict probability of being in the fin market?	$Pr(Y = 1 X) = High\ value\ area_i$
Does total low value fin area predict probability of being in the fin market?	$Pr(Y = 1 X) = Low\ value\ area_i$
Does maximum volume predict probability of being in the fish maw market?	$Pr(Y = 1 X) = Body\ Volume_i$
Does total high value fin area interact with species conservation status to predict probability of being in the fin market?	$Pr(Y = 1 X) = High\ value\ area_i \cdot IUCN_i$
Does total low value fin area interact with species conservation status to predict probability of being in the fin market?	$Pr(Y = 1 X) = Low\ value\ area_i \cdot IUCN_i$
Does maximum volume interact with species conservation status to predict probability of being in the fish maw market?	$Pr(Y = 1 X) = Body\ Volume_i \cdot IUCN_i$
Does total high value fin area interact with species median depth of occurrence to predict probability of being in the fin market?	$Pr(Y = 1 X) = High\ value\ area_i \cdot Depth_i$
Does total low value fin area interact with species median depth of occurrence to predict probability of being in the fin market?	$Pr(Y = 1 X) = Low\ value\ area_i \cdot Depth_i$
Does maximum volume interact with species median depth of occurrence to predict probability of being in the fish maw market?	$Pr(Y = 1 X) = Body\ Volume_i \cdot Depth_i$
Does total high value fin area interact with species distribution quantile to predict probability of being in the fin market?	$Pr(Y = 1 X) = High\ value\ area_i \cdot Dist_i$
Does total low value fin area interact with species distribution quantile to predict probability of	$Pr(Y = 1 X) = Low\ value\ area_i \cdot Dist_i$

being in the fin market?

Does maximum volume interact with species
distribution quantile to predict probability of
being in the fish maw market?

$$Pr(Y = 1|X) = Body\ Volume_i \cdot Dist_i$$

Supplementary Table S5: Inference and prediction Ordered Forest model accuracies by product and end-market countries. ORF = Ordered Random Forest, RPS = Rank Probability Score.

Model type	End-market country	Shark fins		Fish maw	
		Accuracy	RPS	Accuracy	RPS
Inference	China	0.609	0.096	-	-
		-	-	0.389	0.126
	Singapore	0.538	0.103	-	-
	Vietnam	0.622	0.092	-	-
Prediction	China	0.829	0.061	-	-
		-	-	0.598	0.111
	Singapore	0.783	0.069	-	-
	Vietnam	0.815	0.053	-	-