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Supplementary Materials for

The historical development of complex global trafficking networks for marine wildlife

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The PDF file includes:

Other Supplementary Material for this manuscript includes the following:

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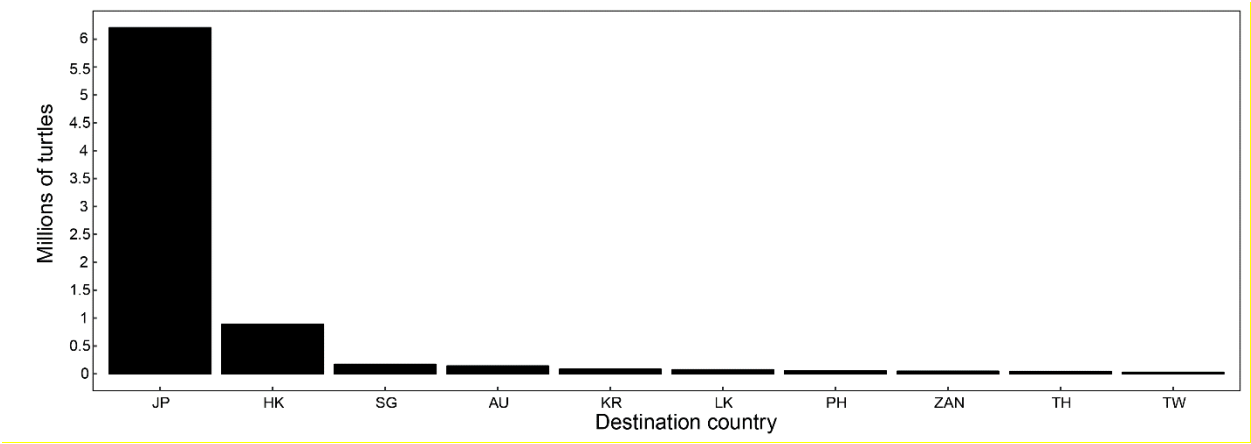

Fig. S1. Japan was the major importer of tortoiseshell from 1844 to 1992. The top ten tortoiseshell-importing countries, listed by descending rank, in millions of turtles. Volumes of shipments that had multiple destinations were redistributed among importing countries proportionate to the volume each imported as a solo destination. Two-letter UN country codes are shown, the full list is provided in Table S2.

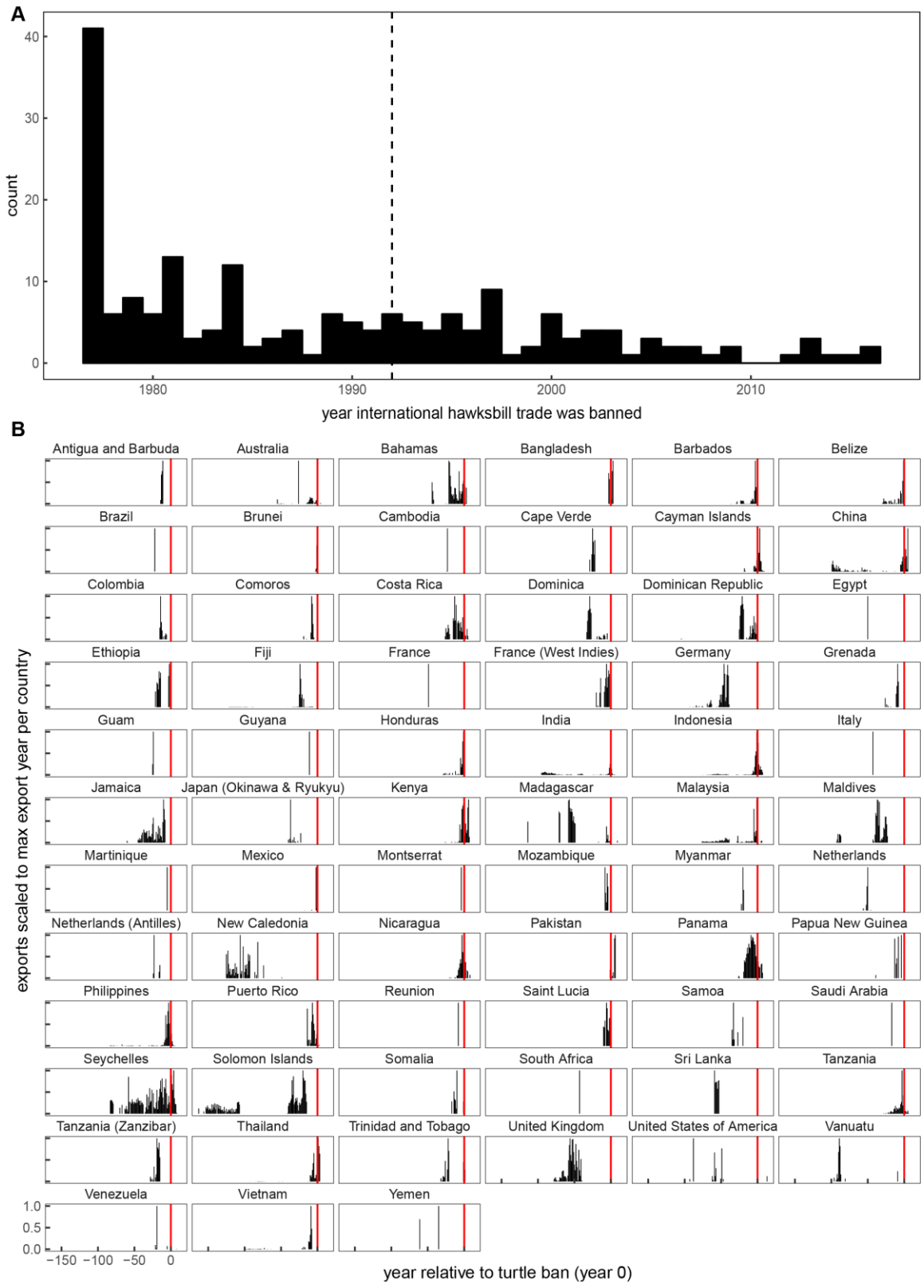

Fig. S2. Turtle exports per country varied in relation to CITES trade ban. (**A**) Year the international trade of hawksbill sea turtles was banned per country. The hawksbill sea turtle was listed globally as an

Appendix 1 species in 1977 for all signatories, making it the earliest ban year. After 1977, international trade was banned for each country through accession to CITES or the end of a CITES reservation. Dashed line indicates the year our dataset ends, the year Japan ended their CITES reservation. (**B**) Turtle exports in relation to trade ban. Export volumes per year are scaled to the maximum annual export per country. The year each country agreed to ban international trade of hawksbill sea turtles, is scaled to year 0, denoted by the red line. Of the countries in our trade dataset, several signatories are not included: Cuba, Palau, and Saint Vincent and the Grenadines continue to have reservations, and Haiti and Turks and Caicos never signed onto CITES.

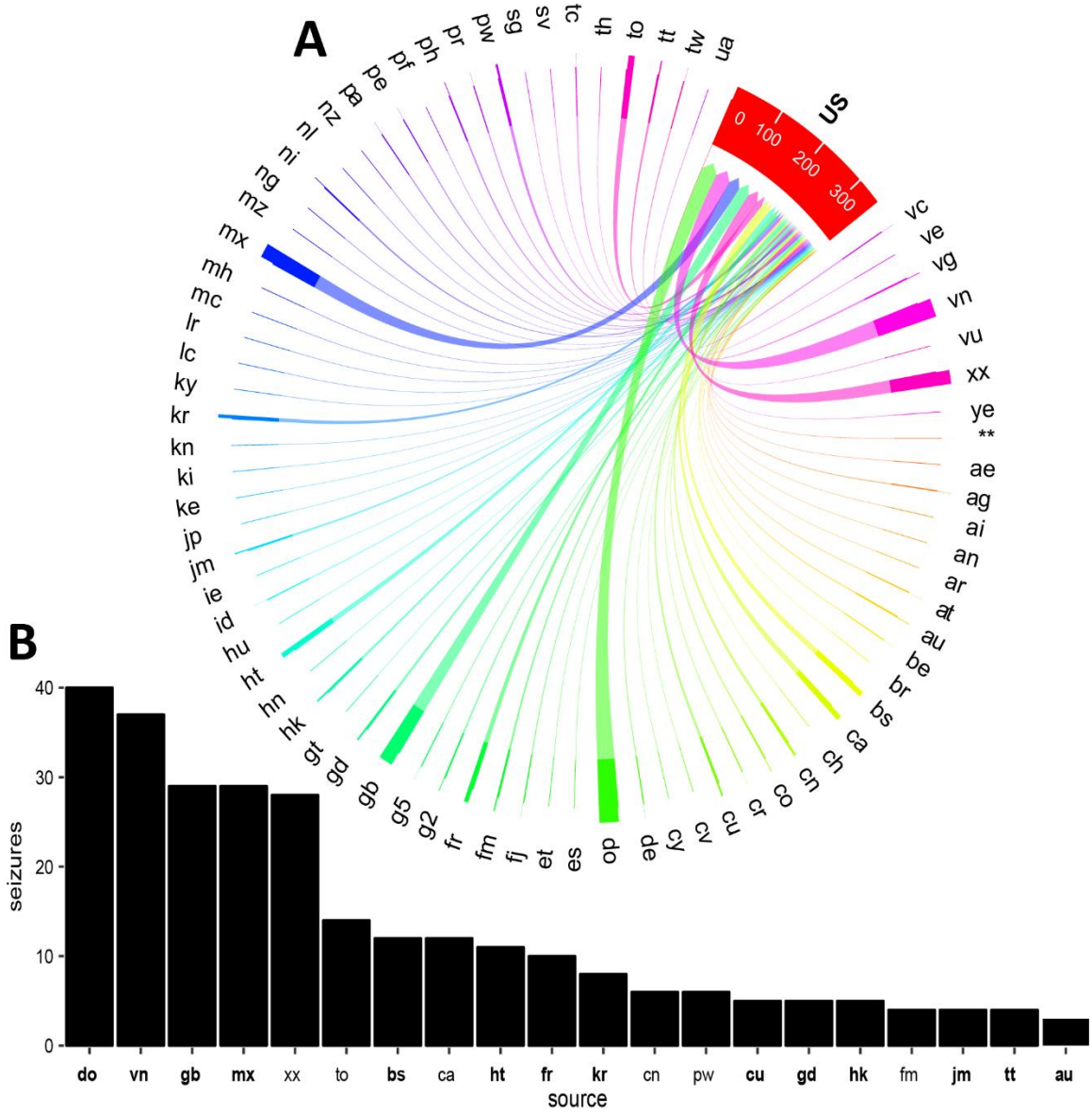

Fig. S3. Illegally trafficked hawksbill sea turtle parts and products are seized entering the United States from more than 70 countries. The global trafficking network remains complex in the modern era, as seen in this segment of trade entering a single country. (**A**) Chord diagram demonstrates trafficking routes between exporting countries and the US. Arrows direct from source country to the US, arrow width is proportionate to the number of seizures. (**B**) Top 20 tortoiseshell-exporting countries to the US, listed in number of seizures. Data are USFWS OLE seizure records at US ports of entry from 1999-2018. Units are number of seizures.

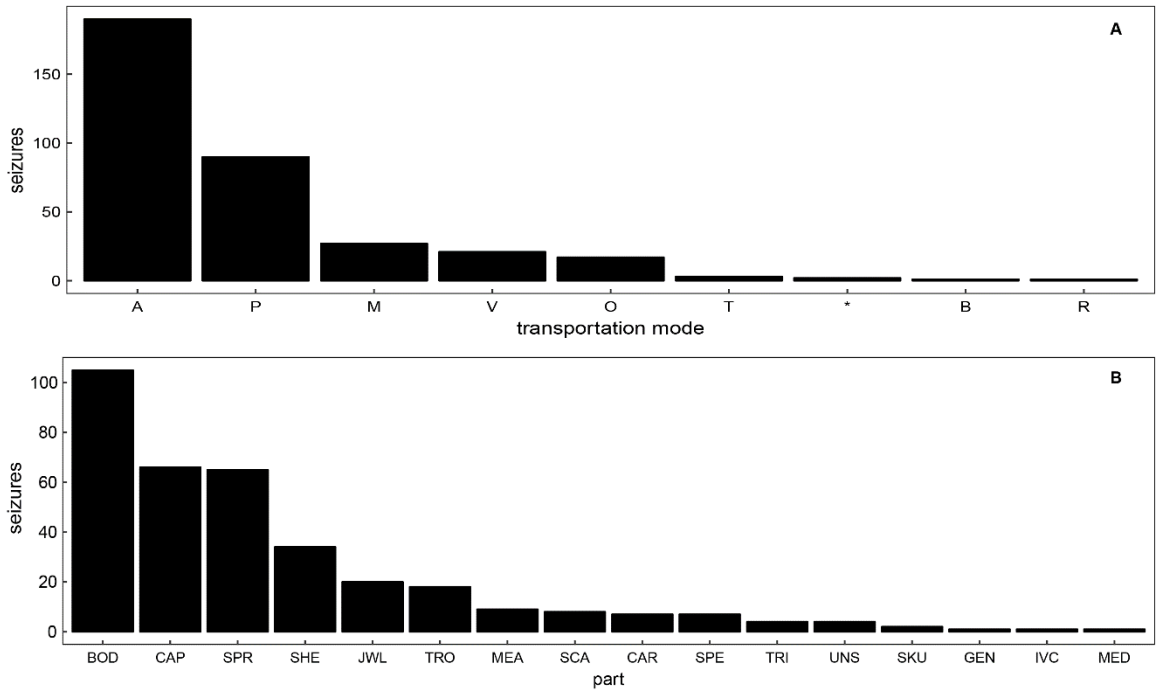

Fig. S4. Seized hawksbill sea turtles are trafficked to the United States largely by air transportation and in raw forms more frequently than processed tortoiseshell. (**A**) Frequency of hawksbill sea turtle seizures at US ports by transportation mode. Transportation modes: A=air cargo, P=personal accompanying baggage, M=mail, V=personal vehicle, O=ocean cargo, T=truck or commercial vehicle, *=unknown, B=border crossing on foot, and R=rail. (**B**) Frequency of hawksbill sea turtle seizures at US ports by part or product. BOD=whole dead animal, CAP=raw or unworked carapace, SPR=shell product, SHE=raw unworked shell, JWL=jewelry, TRO=trophy (all the parts of one animal), MEA=meat, SCA=scale, CAR=carvings, SPE=scientific or museum specimen, TRI=trim (shoe, garment, or decorative), UNS=unspecified, SKU=skull, GEN=genitalia (castrated and dried penis), IVC=ivory carvings, MED=medicinal part or product. Data are USFWS OLE seizure records at US ports of entry from 1999-2018. Units are number of seizures.

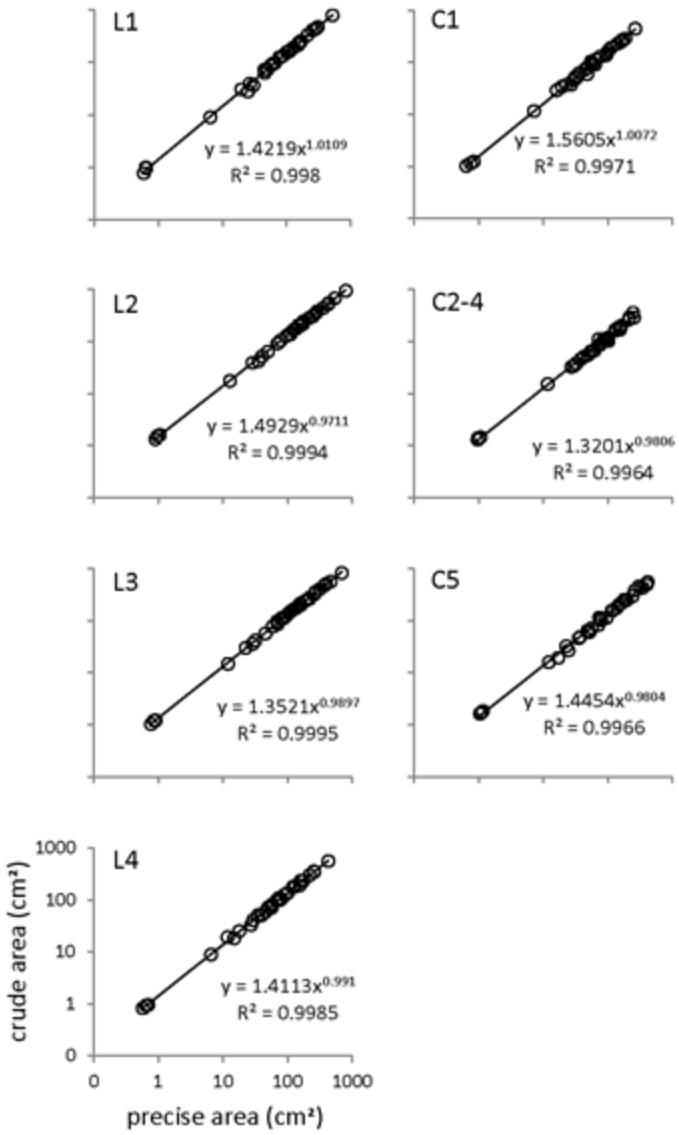

Fig. S5. Power law models show the relationship between calculated precise and crude areas for individual scutes and scute groupings from hawksbill sea turtles. Precise area is the exact scute area calculated by scanning traced scute outlines into ArcGIS, geo-referencing the scans, generating polygons, and calculating their areas. The crude area is a simplistic proxy, composed of the longest length and widest width when each scute is laid flat on a gridded surface. This latter method calculates the area of the rectangle each scute sits within, and therefore necessarily overestimates each scute's area. However, this number characteristically varies in proportion to the true, or precise area (see Fig. 1B), for each scute. The above power law relationships, for all replicates, have $R^2 > 0.996$. These relationships are therefore reliable as a rapid method to assess many scutes – e.g. to assess a large seizure for its contents – to determine their precise area, which in turn can be used to calculate their length and demographic.

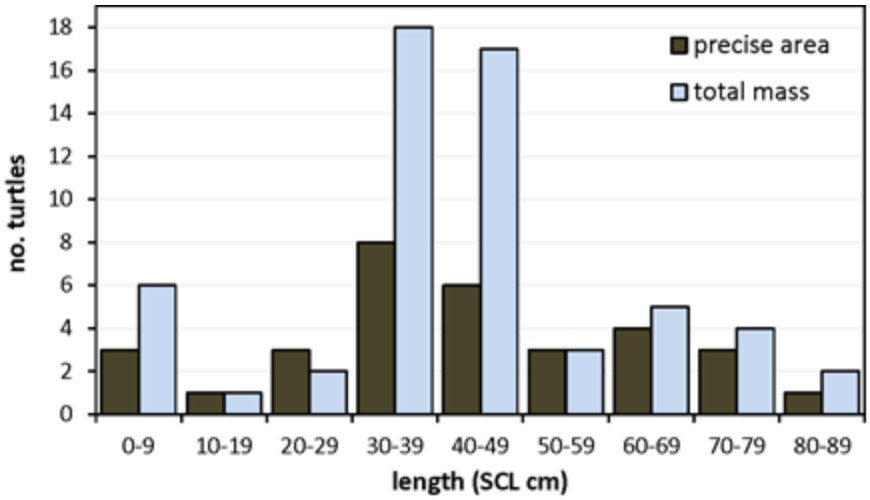

Fig. S6. Hawksbill sea turtle specimens used in this study were a range of sizes. A total of 58 carapaces (light blue columns) from hawksbill sea turtles were obtained from law enforcement seizures and strandings networks. These specimens ranged from 4.1 to 89.1 cm (ave = 42.0, sd = 19.6 cm), representing all demographics from emerged hatchlings to large breeding adults. Like most sea turtle studies, the overall specimen set was dominated by small juveniles that recently have recruited to coastal reef ecosystems. All of these specimens were measured for straight carapace length (SCL), disassociated into individual scute plates, and each scute plate was weighed. Individual scute mass data were summed and related to SCL to develop a general scaling rule for the mass of tortoiseshell an individual turtle of a given length might produce (see Fig. 1C). A subset of this number, 32 carapaces (dark brown columns), were additionally examined for the precise area each scute contains. These area data were used as a basis for understanding the demographic of unlabeled (not containing any further metadata) and disintegrated scute plates obtained from law enforcement.

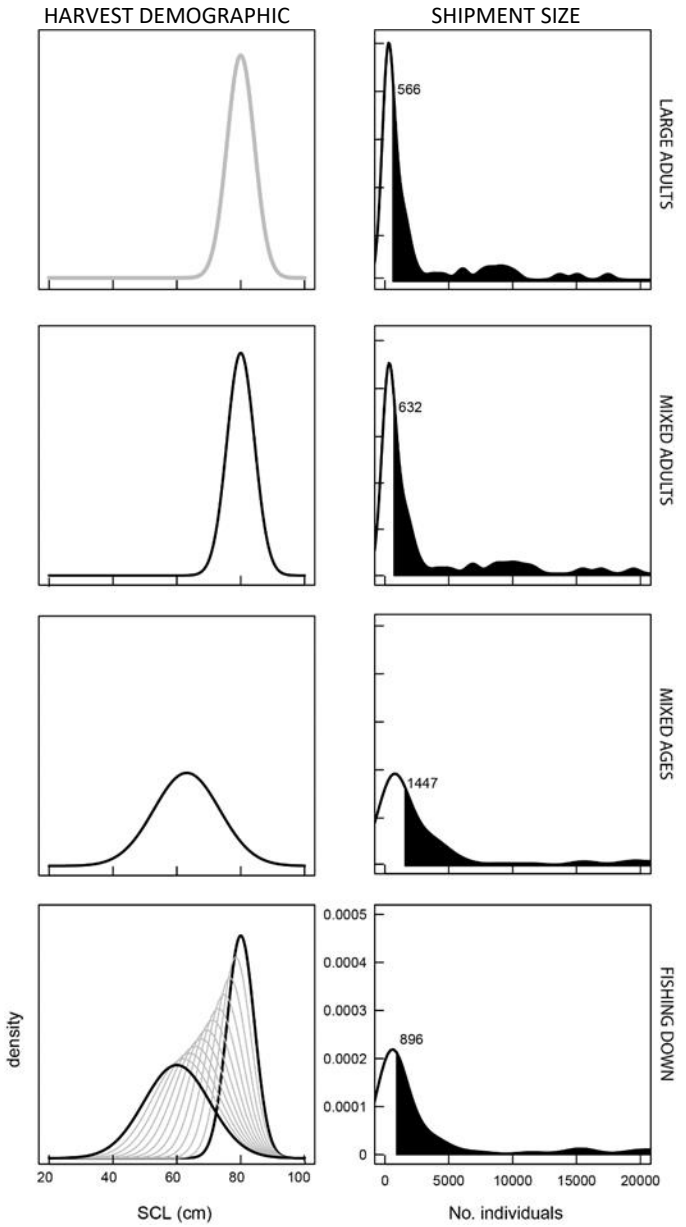

Fig. S7. Demographically explicit scenarios produce different estimates of the number of hawksbill sea turtles harvested. Demographic distributions are shown in the left column for each of the four harvest scenarios. The right column shows an example of the median shipment size in numbers of turtles for the entire time series of exports from the Philippines. Harvest scenarios from top to bottom: Large adults – all harvested individuals were a fixed size of 80 cm SCL, mixed adults – a range of adult sizes were harvested, mixed ages – adults and juveniles were harvested following the demographic distribution of a shipment seized in the 1980s (see Fig. 1), and fishing down – the distribution moves from mixed adults to mixed ages over time following population depletion.

Table S1. Hawksbill sea turtle export data curation methods. Hawksbill turtle export data were obtained from nine published sources (*30*, *48-54*) and Japanese Customs archives. These data included both import and export data. In order to account for re-export, we discarded data from European countries, USA, and Canada after 1950, with the assumption that these data were recorded at the original point of export. For European countries prior to 1950, we reattributed turtles to source basins based on their colonial holdings.

SOURCE COUNTRY	YEARS	KG	COLONIES DURING THIS PERIOD	BASIN REATTRIBUTION
Europe	1936	163	n/a	Split equally
France	1935	259	West Atlantic (Dahomy, Guinea), Indian Ocean (French Somaliland), Oceania	Split between Indian and Pacific
Germany	1884-1949	49931	Indian Ocean (German East Africa), Pacific (Samoa, New Guinea)	Split between Indian and Pacific
Italy	1936	42	Indian Ocean (Italian East Africa)	Indian
Netherlands	1928-1949	15642	Indian Ocean (Dutch East Indies), Atlantic (Curacao, Surinam)	Split between Indian and Atlantic
North America	1918	230	n/a	Split equally
UK	1899-1949	69678	Multiple, all basins	Split equally
USA	1884-1949	5709		Split equally between Atlantic and Pacific

Table S2. Model parameters for tortoiseshell morphometric relationships in Fig. 1. Figure 1 shows the relationships between **(B)** straight carapace length ("SCL") and the area (cm^2) of each scute, as well as **(C)** individual length and total tortoiseshell mass. The model parameters associated with each relationship shown in Fig. 1 are listed below.

FIGURE	TOPIC	SCUTE	MODEL	β0	β1	R^2
Figure 1B	length to scute area	L1	$y = \beta 0 x^{\beta 1}$	0.02713	2.13161	0.994
Figure 1B	length to scute area	L2	$y = \beta 0 x^{\beta 1}$	0.04183	2.14637	0.996
Figure 1B	length to scute area	L3	$y = \beta 0 x^{\beta 1}$	0.03529	2.15432	0.996
Figure 1B	length to scute area	L4	$y = \beta 0 x^{\beta 1}$	0.02661	2.07922	0.991
Figure 1B	length to scute area	C1	$y = \beta 0 x^{\beta 1}$	0.04958	1.85766	0.991
Figure 1B	length to scute area	C2-4	$y = \beta 0 x^{\beta 1}$	0.07777	1.83390	0.991
Figure 1B	length to scute area	C5	$y = \beta 0 x^{\beta 1}$	0.05991	1.92357	0.983
Figure 1C	length to scute mass	all scutes	$y = \beta 0 x^{\beta 1}$	9.04E-07	3.15519	0.979

Table S3. Complete list of United Nations country abbreviations (alpha 2) used in Fig. 4 and figs. S1 and S3. These are available at https://en.wikipedia.org/wiki/ISO_3166-1_alpha-2. Three alpha codes correspond to territories.

ABBREV	COUNTRY	ABBREV	COUNTRY	ABBREV	COUNTRY
AE	United Arab Emirates	GU	Guam	NZ	New Zealand
AG	Antigua and Barbuda	GY	Guyana	OKI	Okinawa
AI	Anguilla	HK	Hong Kong	PA	Panama
AN	Netherland Antilles	HN	Honduras	PE	Peru
AR	Argentina	HT	Haiti	PF	French Polynesia
AT	Austria	HU	Hungary	PG	Papua New Guinea
AU	Australia	ID	Indonesia	PH	Philippines
BB	Barbados	IE	Ireland	PK	Pakistan
BD	Bangladesh	IN	India	PR	Puerto Rico
BE	Belgium	IT	Italy	PW	Palau
BN	Brunei	JM	Jamaica	RE	Reunion
BR	Brazil	JP	Japan	SA	Saudi Arabia
BS	Bahamas	KE	Kenya	SB	Solomon Islands
BZ	Belize	KH	Cambodia	SC	Seychelles
CA	Canada	KI	Kiribati	SG	Singapore
CH	Switzerland	KM	Comoros	SO	Somalia
CN	China	KN	Saint Kitts and Nevis	SV	El Salvador
CO	Colombia	KR	South Korea	SSI	South Sea Islands
CR	Costa Rica	KY	Cayman Islands	STC	St. Croix
CU	Cuba	LC	Saint Lucia	TC	Turks and Caicos
CUR	Curacao	LK	Sri Lanka	TH	Thailand
CV	Cape Verde	LR	Liberia	TO	Tonga
CY	Cyprus	MC	Monaco	TT	Trinidad and Tobago
DE	Germany	MG	Madagascar	TW	Taiwan
DM	Dominica	MH	Marshall Islands	TZ	Tanzania
DO	Dominican Republic	MM	Myanmar	UA	Ukraine
EG	Egypt	MQ	Martinique	US	United States of America
ES	Spain	MS	Montserrat	VC	Saint Vincent Grenadines
ET	Ethiopia	MU	Mauritius	VE	Venezuela
FJ	Fiji	MV	Maldives	VG	British Virgin Islands
FM	Micronesia	MX	Mexico	VN	Vietnam
FR	France	MY	Malaysia	VU	Vanuatu
G2	Unknown	MZ	Mozambique	YE	Yemen
G5	Unknown	NC	New Caledonia	ZA	South Africa
GB	United Kingdom	NG	Nigeria	ZAN	Zanzibar
GD	Grenada	NI	Nicaragua	XX	Unknown
GT	Guatemala	NL	Netherlands	**	Unknown

Additional dataset S1 (separate file)

Dataset S1. Hawksbill sea turtle historical trade records. This dataset contains trade records of tortoiseshell shipments from 1844-1992. Records include the year of shipment, shipment mass (kg), source country, destination country, reference, and record type. Data were obtained from nine published sources (*30, 48-54*) and Japanese Customs archives, and curated (see Table S1).

Additional dataset S2 (separate file)

Dataset S2. Hawksbill sea turtle scute morphometrics. This dataset contains measurements of carapaces from 58 seized and stranded hawksbill sea turtles provided by USFWS Office of Law Enforcement and NOAA Pacific Islands Fisheries Science Center (USFWS permit TE-72088A-0), respectively. Specimens ranged from 4 to 89 cm SCL. Scute mass was calculated per specimen (see Materials and Methods). These data were used to determine the relationship between turtle morphemetrics and scute mass produced.

Additional dataset S3 (separate file)

Dataset S3. U.S. seizure records of hawksbill sea turtles. This dataset contains records of seized hawksbill sea turtle parts and products entering U.S. ports of entry illegally from 1999-2018. The 352 records were obtained from USFWS Office of Law Enforcement (FOIA request #FWS-2018-00548).