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Reconstructing 290 years of a data-poor fishery through ethnographic and archival research: The East Pacific green turtle (*Chelonia mydas*) in Baja California, Mexico

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Abstract

Evaluating historical changes in the exploitation of marine organisms is a key challenge in fisheries ecology and marine conservation. In the Eastern Pacific, marine turtles were exploited for millennia before systematic monitoring began <50 years ago. Using ethnographic and historical data, we generated a detailed reconstruction of the East Pacific green sea turtle (*Chelonia mydas*) fishery in Mexico's Baja California peninsula from 1700 to 1990. Sea turtles from the region's important feeding areas were a staple food source from the earliest phases of human occupation, dating back at least 12,000 years. In contrast with regions such as the Caribbean, small human populations and limited market access resulted in apparently sustainable turtle harvests until the second half of the 20th century. We found that the estimated annual catches between 1960 and 1980 exceeded the estimated annual catches of the previous 250 years by an order of magnitude, leading to the collapse of the fishery and the depletion of the green turtle population. A total ban on sea turtle captures in 1990, comprehensive nesting beach protection, and significant conservation efforts resulted in increases in breeding females on nesting beaches and catch rates in scientific monitoring on main feeding grounds since the early 2000s. This provides a positive outlook for this once-depleted population segment. Although further research is needed to evaluate current conservation status, we have identified a date, between 1950 and 1960, which can serve as a reliable temporal reference for future evaluations of historical baseline abundance in this region.

KEYWORDS
Chelonia mydas, data-poor fisheries, ethnographic data, fisheries reconstruction, marine historical ecology, sea turtle fisheries

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1 | INTRODUCTION

Evaluating long-term trends in marine animal exploitation is fundamental to understanding the current status and trajectories of fisheries and marine megafauna (Harnik et al., 2012; Jackson, 2001; Pauly, 1995; Sáenz-Arroyo, Roberts, Torre, & Cariño-Olvera, 2005). Globally, sea turtles have been exploited for millennia; however, monitoring time frames in the central and eastern Pacific span <50 years (Balazs & Chaloupka, 2004; Bjorndal & Jackson, 2003; Kittinger, Van Houtan, McClenachan, & Lawrence, 2013; Seminoff, 2010). In data-poor scenarios such as this one, historical data and fishers' knowledge are crucial to understanding change over time (McClenachan, Cooper, McKenzie, & Drew, 2015; McClenachan, Ferretti, & Baum, 2012; Sáenz-Arroyo & Revollo-Fernández, 2016; Sáenz-Arroyo, Roberts, Torre, Cariño-Olvera, & Hawkins, 2006; Schwerdtner Máñez et al., 2014; Thurstan et al., 2015). The importance of non-traditional data has increasingly gained attention since the publication of pioneering research such as Jackson et al. (2001) work on the collapse of coastal ecosystems, McClenachan and Kittinger's (2012) reconstruction of reef fish harvests in Hawaii and Florida from historical and archaeological sources, and Sáenz-Arroyo Roberts, Torre, & Cariño-Olvera (2005) use of fishers' perception to reassess the status of the Gulf grouper fishery in the Gulf of California. Using historical sources and fishers' knowledge, researchers have reconstructed fisheries where little or no other data were available (McClenachan et al., 2015; Schwerdtner Máñez et al., 2014; Thurstan et al., 2015). Furthermore, analysing fisheries within a historical perspective can shed light on processes of social and economic change that affect long-term sustainability (McClenachan & Kittinger, 2012).

Humans have used sea turtles for food and medicine as they first arrived in the central desert of the Baja California peninsula, in what is now Mexico, at least 12,000 years ago (Des Lauriers, 2011; Early Capistrán, 2014b). In this region of arid lands and productive seas (Águila Ramírez, Casas Valdez, Ortega García, Núñez López, & Cruz Ayala, 2003; Álvarez-Borrego, 2002), marine resources in general, and East Pacific green turtles in particular, have been essential to human survival. During the 20th century, they were referred to as "the black steer" of Baja California, "the staple and chief source of meat in the barren peninsula" (Caldwell, 1962). Sea turtle exploitation in Baja California has a unique historical trajectory, marked by small human populations and relative isolation from global markets (Early Capistrán, 2014b). This case provides an interesting contrast to regions like the Caribbean, where intensive capture for export led to important declines by the 18th century (McClenachan, Jackson, & Newman, 2006). The singular relationship between humans and turtles, sustained over thousands of years, makes the important green turtle feeding areas of the Baja California peninsula (hereafter, Baja California) an ideal case-study for long-term interactions between humans and marine organisms.

The East Pacific green turtle (*Chelonia mydas*, Cheloniidae) is a regionally distinct population of the circumtropical species *Chelonia mydas*, which is globally the most abundant large marine herbivore (Bjorndal, 1997; Chaloupka et al., 2008; Dutton et al., 2008; NOAA Fisheries 2016). Green turtles are long-lived, slow-maturing, highly fecund, and have a complex life history, occupying various habitats separated by hundreds or thousands of kilometres during different life stages (Seminoff, 2004). The East Pacific population segment nests mainly in the state of Michoacán, in Central Mexico, and to a lesser degree on the Revillagigedo and Tres Marías islands, and spends its juvenile phase and parts of its adult life-span in warm and temperate foraging areas hundreds of kilometres away in the coastal lagoons and bays of Northwest Mexico (Alvarado Díaz, Delgado-Trejo, & Suazo-Ortuño, 2001; Koch, Brooks, & Nichols, 2007; Seminoff, 2010). This East Pacific green turtle (hereafter, green turtle) population declined substantially from the 1960s to the 1990s due to heavy fishing pressure (Clifton, Cornejo, & Felger, 1995; Seminoff, Reséndiz-Hidalgo, Jiménez Reséndiz, Nichols, & Todd-Jones, 2008) and is currently listed as Endangered by the International Union for the Conservation of Nature (IUCN) and by the Mexican government (Secretaría de Medio Ambiente y Recursos Naturales 2010; Seminoff, 2004). Thanks to a strict fisheries ban in place since 1990 and important conservation efforts since then, the population at nesting beaches and foraging areas has increased, and it was reclassified from Endangered to Vulnerable under the United States Endangered Species Act in 2016 (NOAA 2016).

While the green turtle's complex life history—coupled with the lack of detailed, long-term monitoring data—currently prevents reliable calculations of past population levels, fisheries reconstruction could enable the evaluation of human impact over broad time scales and indicate possible inflection points in abundance. In cases such as these, fisheries reconstruction provides insight into unrecorded or unassessed human impacts (McClenachan & Kittinger, 2012; Pauly & Zeller, 2016; Zeller, Booth, Craig, & Pauly, 2006). Likewise, non-traditional data sources are a vital complement to scientific data for understanding long-term change and have often been incorporated in the understanding of data-poor fisheries, providing valuable insights into fisheries reconstruction, history, management and status that may otherwise not be available (Johannes, 1981; Kittinger et al., 2011; Sadovy & Cheung, 2004; Sáenz-Arroyo et al., 2006).

Worldwide, studies incorporating non-traditional data have revealed important processes of long-term change which would be unaccounted for if analyses were limited to experimental data (Jackson et al., 2001; Lotze & Worm, 2009; McClenachan et al., 2015). We have expanded upon previous work in fisheries reconstruction and marine historical ecology by incorporating ethnography—a staple method in social anthropology (Bernard, 2011)—which allowed us to reconstruct, in detail, sea turtle captures in a key region over 290 years. Using place-based empirical knowledge—gathered over generations of direct empirical observation (Aikenhead, 2006; Cajete, 2004)—historical records and other non-traditional data compiled through ethnography and historiography, we have developed a detailed reconstruction of the green turtle fishery at two locations in the central desert of Baja California from 1700 to 1990; for 93% of the chronology, no other data existed. The environmental history of green turtle capture in the central desert differs substantially from that of other regions, such as the Caribbean or the Central Pacific, and provides an opportunity to evaluate the effects of different historical trajectories on long-term human impacts on sea turtles (Kittinger et al., 2013; McClenachan & Kittinger, 2012; McClenachan et al., 2006). We expect that the incorporation of ethnography into fisheries reconstruction will be useful for evaluating human impacts on marine organisms when scientific and/or capture data are scarce or non-existent, as is the case of many fisheries on a global scale.

2 | METHODS

2.1 | Study area

At a regional level, the study area comprises ~14,400 km^2 in the central desert, and comprises two important *C. mydas* feeding areas with key contributions to the 20th century fishery in the modern-day communities of Bahía de los Ángeles, Baja California (28°57′N, 113°33′W), on the Gulf of California, and Guerrero Negro, Baja California Sur (27°57′N, 114°3′W), on the shores of Laguna Ojo de Liebre (hereafter, Laguna Ojo de Liebre). These constitute the two primary study locations. Both sites are warm-temperate feeding areas where *C. mydas* is the predominant sea turtle species, have a shared cultural and economic history, and were important contributors to the commercial green turtle fishery during the 20th century (Early Capistrán, 2014b; Koch, 2013; Seminoff, Resendiz, & Nichols, 2002). The study area also includes the adjacent regions historically under the administration of the missions of San Borja and Santa Gertrudis in the 18th and 19th centuries. Additional fieldwork was conducted at said mission sites and the former mining communities of El Arco and Campo Alemán (Figure 1).

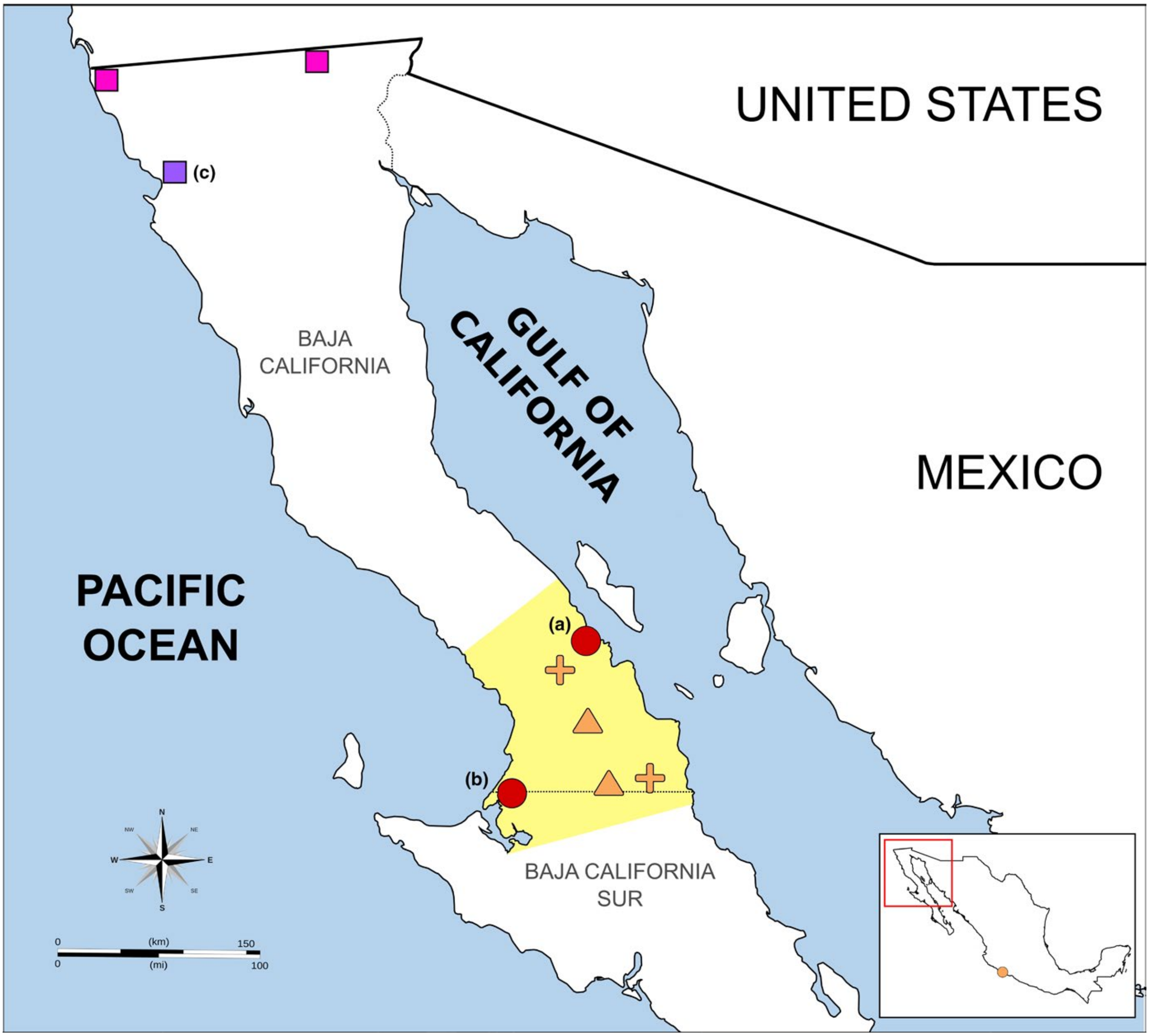

FIGURE 1 Map of study area. Primary research sites, Bahía de los Ángeles (a) and Guerrero Negro/Laguna Ojo de Liebre (b), are in red (circles). Secondary research sites—missions (crosses) and mining communities (triangles)—are in orange. Commercial centres are represented with rectangles. The primary commercial site, Ensenada (c), is in purple and secondary commercial sites are pink. The orange circle in the inset map represents the index nesting beach at Colola, Michoacán. The shaded area represents the limits of the study region, and the dotted line represents the current administrative divisions between the states of Baja California and Baja California Sur. [Colour figure can be viewed at wileyonlinelibrary.com]

2.2 | Ethnography

There is an important body of work on the use of fishers' knowledge (Johannes, Freeman, & Hamilton, 2000; Sáenz-Arroyo & Revollo-Fernández, 2016; Sáenz-Arroyo, Roberts, Torre, & Cariño-Olvera, 2005) and local ecological knowledge for fisheries research (Beaudreau & Levin, 2014; Huntington, 2000). We have built upon the methods developed by Sáenz-Arroyo, Roberts, Torre, & Cariño-Olvera (2005) and Sáenz-Arroyo, Roberts, Torre, Cariño-Olvera, & Enriquez-Andrade (2005) for quantifying fishers' knowledge gathered through semi-structured interviews, by incorporating an ethnographic approach—in terms of methods and epistemology (Bernard, 2011; Denzin & Lincoln, 1994; Guber, 2015)—to data collection and analysis. We used ethnography to gather detailed, long-term information which informed our parameter calculations, provided hard data for capture reconstructions, and helped provide broad narratives of environmental and social change. Furthermore, we hope to advance the integration of culture to marine historical ecology (Anderson, 2006; Bolster, 2006; Van Sittert, 2005).

Ethnography is a holistic approach to the study of a social system, which includes qualitative and quantitative methods and has distinctive epistemological characteristics (Bernard, 2011). Ethnographers study social systems, rather than isolated phenomena (Guber, 2015; Harris, 2001). This requires an open-ended approach, in which data are gathered broadly over topic areas and new questions are continually developed over the course of fieldwork (Guber, 2015). Ethnographers attempt to understand social systems from an "emic" perspective: from the ethnographic contributors' point of view, based on their explanations, categories and observations. This requires establishing rapport with communities, working with sensitivity to the social group's rules and norms, and developing an understanding of the social system on its own terms. Ethnographers also include "etic" perspectives: the researcher's accounts, categories and explanations (Harris, 2001). This requires ethnographers to collect data, comment on both facts and data collection, and carry out meta-analysis of both processes (Table 1). These analyses and meta-analyses help identify biases, both those of the ethnographic contributors and the researchers (Bernard, 2011; Guber, 2015).

Ethnographers use a varied toolkit distinguished by participant observation, in which the researchers immerse themselves in a social group as an active participant during extended periods of time (weeks, months or years; Table 1). Over the course of 106 working days and 1,696 person-hours of ethnographic fieldwork in 2012 and 2013, two of us (M.M.E.C. and G.G.M.) conducted participant observation and informal (n = 186), semi-structured (n = 33) and in-depth interviews (n = 20) in the communities of Bahía de los Ángeles and Guerrero Negro, compiled 2,003 pages of field journals, video recordings (n = 63), audio recordings (n = 59), historical photographs (n = 31), ethnographic photographs (n = 212) and collaborative maps (n = 32). All audio recordings, video recordings and photographs were gathered with contributors' informed verbal consent. We recorded field notes and journals in as much detail as possible and covered all observations, beyond the principal research topics. We systematized, coded and indexed all data captured in the field, and separated observations from analysis and commentary (Bernard, 2011; Denzin & Lincoln, 1994; Table 1; Supporting Information, Section 1, Table S1). Fieldwork was carried out in accordance with the Code of Ethics of the Latin American Society of Ethnobiology (Sociedad Latinoamericana de Etnobiología 2014).

TABLE 1 Characteristics of ethnography

Approach	Holistic study of a social system
	Thick description: explaining phenomena as well as context
	Integration of "emic" (ethnographic contributors' explanations, categories, observations) and "etic" (researcher's explanations, categories, observations) perspectives
	Data collection, commentary on both data and data collection, meta-analysis
Toolkit	Participant observation: immersion in a social group as an active participant, all observations recorded in detail in field journals and then indexed, coded, and categorized
	Structured, semi-structured, in-depth, informal, and open-ended interviews
	Oral history and life histories
	Mapping and collaborative mapping
	Technical photography
	Photojournalling
	Audio recording
	Video recording
	Questionnaires and surveys
	Statistical analysis
	Textual analysis

Through a deliberate hierarchical sampling method, we worked in-depth with experts on green turtle fishing, commerce and processing (Bernard, 2011). In each community, we interviewed over 90% of living fishers who participated in the legal sea turtle fishery before 1990, using the above-mentioned methods for broad data collection and integrating recurring questions based on those of Sáenz-Arroyo, Roberts, Torre, & Cariño-Olvera (2005) and Sáenz-Arroyo, Roberts, Torre, Cariño-Olvera, & Enriquez-Andrade (2005) to obtain systematic quantitative data on sea turtle captures (Tables 2, 4 and 5; Supporting Information, Section 1, Table S2). We used verification methods such as cross-questioning, independent corroboration of data between contributors and data sources (oral, written, visual, etc.), and electronic data capture, as well as familiarity generated by extended stays in communities (Bernard, 2011; Denzin & Lincoln, 1994; LeCompte & Goetz, 1982). This multifaceted approach generated detailed and cross-referenced information that could not be obtained through closed questions or surveys alone, and helped identify biases by analysing data within the social, cultural and historical context in which they were generated (Bernard, 2011; Denzin & Lincoln, 1994; LeCompte & Goetz, 1982).

We must point out that ethnography has important limitations. Social systems are inherently complex, and the number of variables involved in their observation and analysis makes specific approaches to each study an inherent necessity in ethnographic research: different tools and theoretical approximations are required in each case (Bernard, 2011; Guber, 2015). For example, if we were to conduct this same study across the Gulf of California, with the Comcáac (Seri) nation, we would need at least a functional grasp of a new language (Cmiique Iitom) and would require far more time in the field (a year or more) to understand "emic" categories and touch upon the subtleties of deeply embedded cultural links between humans and turtles (Bernard, 2011; Nabhan, 2003). Ethnography also requires long time spans for fieldwork, data processing (transcription, indexing, categorizing and coding) and analysis (Bernard, 2011; Denzin & Lincoln, 1994). Finally, ethnographic data are primarily qualitative (Bernard, 2011). However, by integrating this approach with existing methods for quantifying fishers' knowledge (Sáenz-Arroyo, Roberts, Torre, & Cariño-Olvera, 2005; Sáenz-Arroyo, Roberts, Torre, Cariño-Olvera, & Enriquez-Andrade, 2005), we hope to expand upon the methodological frameworks available in marine historical ecology.

2.3 | Historiography

Building upon the methods of marine historical ecology (McClenachan et al., 2015; Sáenz-Arroyo et al., 2006; Thurstan et al., 2015), we carried out archival research in 24 libraries and online archives, analysing texts in Spanish, English, French, Latin and Classical Greek (Supporting Information, Section 2). The last two languages were included because (i) many early descriptions of the American continent were written in Latin, as it was a common language of Early Modern scholarship (Gordin, 2015); and (ii) to better understand the context in which these documents were produced, we consulted works by Classical, Mediaeval and Renaissance naturalists that informed the taxonomic categories and epistemological frameworks used by the Jesuit missionaries in their descriptions of the study area (see Supporting Information for a full list of historical and archaeological sources).

We consulted 263 historical documents. Using a strict selection process described in the following paragraphs, we compiled 31% of these documents for in-depth analysis ($n = 83$) and used 11% as quantitative data sources ($n = 29$). We compiled primary sources ($n = 57$), as well as secondary sources and historical publications ($n = 26$) covering dates from 1539 to 1976. We read documents critically, analysing their internal and external validity based on hermeneutic and semiotic analysis (Denzin & Lincoln, 1994), with sensitivity to the social, political and historical context in which they were generated and considering the impact of cultural contact, conquest and colonialism as historical processes that can bias texts (Brettell, 1998). We identified sources of bias (observer bias, informer bias and authorial ethnocentrism) by systematically analysing who collected the data; how, why, under what conditions the information was produced or collected; and towards whom the texts were directed (Bernard, 2011; Brettell, 1998; McClenachan et al., 2015).

We restricted quantitative data sources to first-hand accounts based on systematic observation pertaining to the study region or to warm-temperate *C. mydas* feeding areas in Baja California, using either primary sources or published compilations or scholarly works which met these criteria. These include birth and death records, historical census data, ships' logs, historical scientific literature, commercial records, customs records and mining reports (Tables 3, 4 and 5; Tables S4 and S6). This strict selection process limited quantitative data to a small number of robust sources. Primary sources not based on systematic observation (such as traveller's logs or letters) or related to a broader geographical scope (North-Eastern Pacific or Gulf of California) were read critically and used as qualitative references, along with secondary sources, historical and historiographical publications (See Supporting Information for a full list of historical and archaeological sources). We used qualitative sources to establish a long-term narrative and a theoretical framework for environmental change; to select and define analytical categories and parameters used for harvest reconstruction; to inform parameter calculations; and to corroborate information through comparative analysis.

2.4 | Consumption reconstruction

We compiled quantitative and qualitative data on sea turtle captures, consumption, processing and trade—as well as human population demographics—from ethnographic, historical and archaeological sources (Tables 2, 3, 4 and 5) for four broad time periods: Pre-Hispanic (1700–1750), Mission (1750–1850), Secular (1850–1945) and Modern Fisheries (1945–1990). We used these data sources to calculate per capita and aggregate regional sea turtle consumption over time.

Using paleonutritional data, modern nutritional data and ethnographic data, we estimated per capita sea turtle consumption for the first three periods using the following equation adapted from Early Capistrán (2014b):

$$c_t = (Q\gamma)/[(\lambda p)(1-\delta)] \tag{1}$$

where c_t is the approximate annual per capita consumption of *C. mydas* (turtles person^{-1} year^{-1}) in year t, Q is approximate annual per capita meat consumption for a human population (kg person^{-1} year^{-1}), γ is the percentage of annual meat consumption from sea turtles, λ is the percentage of sea turtle tissue consumed, p is the mean weight of a green sea turtle in the region (kg per turtle), and δ is the percentage of change in weight due to processing (Table 4).

We used the mean nutritional value of muscle and adipose tissue of *C. mydas* (864.3 kcal/kg) to calculate the contribution of sea turtles to local diets (González Olmedo et al., 2004). We calculated the percentage of sea turtle tissue consumed (λ) using percentage values grouped by category (fillet meat, offal, fats, etc.) from a commercial report of *C. mydas* processing (Márquez, Elizalde, & Nodarse, 1991), and summed the categories used. Values for p were based on

TABLE 2 Examples of quantitative data obtained from ethnographic sources. Bold type shows data used to reconstruct harvests

Contributor	Age	Location	Quote
Fisherman	76	Laguna Ojo de Liebre	[The Cooperative] would turn in **five or six tonnes a week** [...] I'm talking about a lot of animals, about **80, 90, 100 animals a week** [...] This was around **1967, 1968, 1969**
Fisherman	67	Laguna Ojo de Liebre	[After the highway was built] in the **summer**, a buyer would come **every day, at least every three**. In the **winter** they came **every five or six days**.
Fisherman	82	Laguna Ojo de Liebre	We'd make the trip with **100 kilos of jerky** [...] That was about **25 or 30 turtles**, we'd get **3 or 4 kilos from each one** [...] In summer, it would take about **2 or 3 days to get that many turtles** [...] We'd go to El Arco about **every two or three weeks**.
Merchant	70	Laguna Ojo de Liebre	Before the highway you couldn't make more than **two trips a month** [...] The trucks were **three tonnes**, 12–14 feet long. They carried **three rows of turtles**.
Fisherman	62	Bahía de los Ángeles	Most of the meat we ate was sea turtle. We'd eat it **two or three times a week**

TABLE 3 Examples of quantitative data obtained from historical sources. Bold type shows data used to reconstruct catches

Source category	Title and date	Location	Quote
Whaling logbook	Journal of the Bark *Ocean Bird*, 24 November, 1859	Laguna Ojo de Liebre	**One boat** *was off turtling [...] she came on board with* **four turtle** *and 20 curlew*
Newspaper article	*San Francisco Alta California*, 11 February, 1871	Laguna Ojo de Liebre	*Arrived, schooner* Cygnet, *from* **Scammon's Lagoon**, *with* **100 turtle**; *forty of them will be shipped direct to Chicago.*
Magazine article	*Pacific Fisherman*, December, 1920	Laguna Ojo de Liebre	*Our stay at the lagoons was* **three days** *and we brought back a cargo of* **350 turtles**

scientific monitoring data and corroborated with ethnographic data. Additionally, we calculated δ based on ethnographic data and food processing research (ONU-FAO 1990). We calculated values for γ and λ for different time periods, adjusting for varying dietary patterns among inland and coastal subpopulations. For Pre-Hispanic and Mission Periods, we obtained parameter values from published archaeological research and historical sources; for the Secular and Modern Fisheries Periods, we used published nutritional research (Garry, Passmore, Warnock, & Durnin, 1952; ONU-FAO 2003), historical documents and ethnographic data (Tables 4 and 5; detailed descriptions of parameter calculations are available in Supporting Information, Section 3.1, Tables S3–S5).

For the Pre-Hispanic Period, we used paleonutritional data based on stable isotope analysis for two Cochimí populations (Bahía de los Ángeles and Sierra de San Francisco;King, 1997), in conjunction with ethnohistoric data on Pre-Hispanic diet in the central desert of Baja California (Aschmann, 1959) to calculate dietary composition. These sources register proportional consumption, by weight and caloric density, of different food groups and edible taxa (marine vertebrates, marine invertebrates, terrestrial fauna, legumes, etc.), including sea turtles. We correlated these data with dietary data compiled from hunter-gatherers worldwide (Cordain et al., 2000) to obtain approximate calculations of dietary composition, in terms of kg person^{-1} year^{-1} (Supporting Information, Section 3.1.2, Equation S1). In this desert context, many staple plant foods were seasonal (cactus fruits from *Lemairocereus thurberi* and *Machareocereus gummosus*) or required extensive processing (such as the hearts of agaves, *Agave* spp., which are rendered edible only after roasting in pits for a minimum of a day; Aschmann 1959, King, 1997). In contrast, marine resources were productive and reliable, and made up a significant proportion of the diet (King, 1997).

We calculated *Q* by adding approximate annual consumption values for main sources of animal protein (marine vertebrates, marine invertebrates and terrestrial animals) to obtain approximate annual meat consumption for coastal (500 kg person^{-1} year^{-1}) and inland populations (192 kg person^{-1} year^{-1}), and used interpolated weight and nutritional density values reported by King (1997) and Aschmann (1959) to calculate the percentage of annual meat consumption from sea turtles (γ; Table 4). The very high values of animal protein consumption are consistent with a non-agricultural economy, based heavily on the use of marine resources. We corroborated both *Q* and γ values with 19th century ethnographic reports (McGee, 1898) of

TABLE 4 Consumption reconstruction parameter values and estimates

Period	Consumption reconstruction (Equations 1 and 2)							
	Q (kg person^{-1} year^{-1})	γ^a	λ^b	δ^c	p (kg/turtle)	n_t (people)^d	c_t (turtles person^{-1} year^{-1})	C_t (turtles per year)
Pre-Hispanic (1700–1750)	192, 500	3.5%, 14%	71%	0	43, 50	1950, 2000	0.19–2.29	535–740
Mission (1750–1850)	192, 500	3.5%, 14%	71%	0	43, 50	150–1894	0.19–2.29	8–352
Secular (1850–1945)	97	7%, 43%	45%, 71%	0, 80%	43, 50	3–1000	0.22–1.7	1-(1,682)
Modern Fisheries (1945–1990)	97	7%, 43%	45%, 71%	0, 80%	43, 50	250–4050	0.22–1.7	282–975
Equations used to calculate parameter values	S1	–	–	–	–	S2	–	–
Data source	A, E, H, S	A, C, H, S	E, H, S	E, C	E, M	A, E, H	A, E, H	
Assumptions	All captures correspond to *C. mydas* Inland and coastal subpopulations had distinct dietary patterns All dietary patterns remained stable during each historical period Inland and coastal subpopulations had distinct dietary patterns Sea turtle consumption patterns remained stable from the Pre-Hispanic to the Mission Period Dietary patterns remained stable from the Secular to the Modern Fisheries Period Mean sea turtle weight was constant across time periods							

A, Published archaeological research; C, Published nutritional and commercial reports; E, Ethnographic data; M, Scientific monitoring data; H, Historical/ethnohistorical sources; S, Published scientific research. Ranges of values are indicated by a hyphen, individual values are separated by commas, – indicates not applicable. Outlying values (±2SD) are shown in parentheses.

[a]Percentage of annual meat consumption from sea turtles.

[b]Percentage of sea turtle tissue consumed.

[c]Percentage of change in weight due to processing.

[d]Population values for calculations (either location) are the sum of two subpopulations (coastal and inland).

TABLE 5 General chronology of sea turtle use in the Central Desert of Baja California

	Pre-Hispanic Period (12000 B.P.- 1750)	Mission Period (1750–1850)	Secular Period (1850–1945)	Modern Fisheries Period (1945–1990)
Regional population[a]	3950	Max: 3950 Min: 346	Max.: 1000 Min.: 7	Max.: 9300 Min.: 240
Key characteristics and historical events	Small hunter-gatherer populations	Integration into New Spain Massive deaths of native peoples due to disease, forced sedentarization	Integration to independent Mexico (1822) Secularization of mission lands (*c.* 1850) Large-scale land, fishing, and mining concessions to foreign companies	Large-scale commercial sea turtle fisheries in Mexican Pacific Introduction of motors, turtle nets, fibreglass vessels Increased communication Rapid growth of cities on Mexico-U.S. border Total ban on sea turtle captures (1990)
Sea turtle use patterns	Subsistence	Subsistence	Subsistence/ Commercial	Subsistence/Commercial
Non-traditional data source categories and number of sources used[b,c]	A (n = 24), H (n = 30)	A (n = 24), H (n = 38)	E (n = 107), H (n = 44)	E (n = 320), H (n = 9)

A, Published archaeological research; E, Ethnographic data; H, Historical/ethnohistorical sources.
[a]Maximum and minimum estimated aggregate population values for the region during the period.
[b]For ethnographic data, one source is defined as one journal entry, interview, audio recording, video recording, image or map.
[c]Some sources were used for multiple periods.

the diet of the Comcáac (Seri), an indigenous nation of the Gulf of California, which, like the Cochimí, had a hunting, gathering and fishing economy in a desert landscape (Aschmann, 1959). Given the difficulty of quantifying dietary patterns in through the archaeological record, in particular among hunter-gatherer groups whose diet varied widely in relation to resource availability, this should be considered a broad estimate.

For the Secular Period and Modern Fisheries Period, we based values and parameter consumption on ethnographic and historical data, and adjusted for varying dietary patterns at inland and coastal sites. Dietary patterns had shifted drastically by this period due to the introduction of extensive cattle ranching, small-scale horticulture and non-perishable plant-based food items such as rice, beans, and wheat flour which became staple foods (Crosby, 2010). We calculated annual per capita meat consumption by adjusting mean values for the Baja California peninsula reported by ONU-FAO (2003) for the reported caloric intake of miners, who made up most of the regional population (Garry et al., 1952), such that Q = 97 kg person^{-1} year^{-1}. We calculated the percentage of consumed meat obtained from sea turtles (γ) based on mean values of frequency of sea turtle consumption obtained through ethnographic research. In coastal communities, sea turtles were a staple protein source consumed up to three times per week (γ = 43%), and an important source of dried meat in inland communities (γ = 7%; Table 4); other sources of protein included beef, fish, marine invertebrates and wild game.

We estimated total annual consumption by multiplying per capita consumption by human population size using the following equation adapted from Early Capistrán (2014b):

$$C_t = c_t n_t \tag{2}$$

where C_t is the aggregate sea turtle consumption by a human population during year t (turtles per year) and n_t is human population size during year t (humans). For the Pre-Hispanic and Mission Periods, we used demographic data from published archaeological research and historical sources (Supporting Information, Section 3.2.1, Equation S2, Tables S3, S4 and S6). We calculated population change outside mission settlements by interpolating late Pre-Hispanic population density data with mission records (Supporting Information, Section 3.2.1), For the Secular and Modern Fisheries Periods, we obtained demographic data from historical documents and ethnographic sources (Supporting Information, Section 3.2.2; Tables S5 and S6). We reconstructed consumption until the approximate peak years of the commercial fishery (1965 in Bahía de los Ángeles and 1975 in Laguna Ojo de Liebre; all demographic calculations and population data are available in Supporting Information, Section 3.2, Tables S7–S9).

We assumed that all captures correspond to *C. mydas* given the region's importance as a feeding area; regional and global market preference for the species; and the species' condition as the target of the 20th century commercial fishery in the study area, as confirmed by fishers and merchants (Early Capistrán, 2014b; Márquez, 1996; Seminoff, 2010). While hawksbill turtles (*Eretmochelys imbricata*) were fished commercially in the Gulf of California for their shells, their taste was considered inferior to green turtles, and they were not targeted for human consumption (Márquez, 1996; Sáenz-Arroyo et al., 2006) nor captured systematically in the study area (Early Capistrán, 2014b). We assumed that mean sea turtle weight was constant across time

TABLE 6 Estimated commercial sea turtle harvests from Laguna Ojo de Liebre (Secular Period)

	Estimated harvest by whalers[a]		Estimated imports to California[b]	
	Year	Turtles per year	Year	Turtles per year
	1858	99	1887	183
	1859	444	1917	232
	1860	543	1918	295
	1861	395	1919	2686
	1862	148	1920	810
	1863	148	1921	105
	1864	148	1922	32
	1865	49	1923	2
	1866	99	1924	0
	1867	0	1925	0
	1868	0	1926	0
	1869	49	1927	53
	1870	49	1928	21
	1871	99	1929	0
	1872	0	1930	63
	1873	99	1931	53
			1932	21
			1933	21
			1934	5
			1935	0
Equations used for reconstruction	3; S3			
Assumptions	Reported catches are representative of the fleet All captures correspond to *C. mydas*		1887–1918: 1/3 of landings correspond to study site 1919–1935: All landings correspond to study site	

[a]Sources: Daily Alta California (1860, 1871); Henderson (1972); Scammon (1859/1970).
[b]Sources: Karmelich (1935); Radcliffe (1922); True (1887).

periods. We based our values on scientific monitoring data, corroborated with the mode weight reported by fishers as far back as 1940. We make this assumption despite the possibility that size frequency declined with fishing effort because we do not have sufficient data to adjust for this pattern. However, we consider it to be an appropriate assumption given the limitations of the data.

We assumed that dietary patterns remained stable within each historical period, and that inland and coastal subpopulations had distinct, but stable, dietary patterns. We assumed that sea turtle consumption patterns remained stable from the Pre-Hispanic to the Mission Period for two reasons: (i) the adverse conditions for agriculture resulted in famines rather than broad-scale dietary shifts (Aschmann, 1959; Rodríguez Tomp, 2002); and (ii) because of massive demographic loss during this period, the effect of contingent dietary changes would not have been significant for calculations. For the Secular Period, we assumed that dietary patterns obtained from ethnographic data could be extrapolated as far back as the 1850s, given the region's extreme geographic isolation and confirmation from ethnographic contributors that technological conditions and means of communication had changed little between the 1950s and the previous two generations.

2.5 | Commercial reconstruction

We used official landing records when available. However, official data exists only for a series of 20 years (1962–1982) at Bahía de los Ángeles and 20 years (1887 and 1917–1935) at Laguna Ojo de Liebre respectively. These 40 years of official fisheries data represent 7% of the cumulative chronology (290 years at each location, for a total of 580 years). For this reason, we relied primarily on historical and ethnographic data to reconstruct commercial captures, and our methods allowed us to develop a reconstruction where no other data were available. As different sources reported landings in different units (pounds, kilograms and tonnes), all commercial captures were standardized to turtles per year by converting the annual catch volume to kg per year and dividing by p.

For the Secular Period, we reconstructed commercial captures from Laguna Ojo de Liebre using multiple historical data sources. Sea turtles were captured opportunistically by whalers for food and commerce (Drew et al., 2016; Henderson, 1972). From 1858 to 1873, we used published whaling logbooks (Scammon, 1859/1970), shipping reports (Daily Alta California 1860, 1871) and published research on whaling in Baja California (Henderson, 1972; Vernon, 2009) to compile data on whaling activity and estimate sea turtle captures by American and Russian whalers in Laguna Ojo de Liebre. We assumed that reported catches were representative of the fleet, and that all catches corresponded to *C. mydas* based on taste preferences (Henderson, 1972; See Supporting Information, Section 4, Equation S3 for a detailed description of data standardization). To calculate the approximate annual harvest by the whaling fleet in a given year, we developed the equation:

$$R_t = \mu_w S_t \tag{3}$$

where R_t is the mean approximate annual harvest by the whaling fleet (turtles per year) in year t, μ_w is the mean approximate annual harvest per ship (turtles ship^{-1} year^{-1}), and s_t is the number of ships in the lagoon in year t (ships; Table 6). We obtained vessel counts (s_t) from records compiled by Henderson (1972), and used published logs and shipping reports to estimate catch (μ_w) (Daily Alta California 1860, 1871; Scammon, 1859/1970).

For years 1887–1935, we used customs and landings data for green turtles imported to California from Mexico—almost exclusively from Baja California—to calculate approximate commercial harvests (Karmelich, 1935; Radcliffe, 1922; True 1887), which we standardized to turtles per year. For most of the 19th and early 20th century, turtle capture was opportunistic rather than the result of a dedicated fishery (Averett, 1920; Karmelich, 1935; O'Donnell, 1974), and documentation for this period was scarce. Import and export records provide centralized information, which we analysed in conjunction with landing reports and commercial publications. We used historical records to establish a narrative of changes in capture, market dynamics and spatial extent, and to estimate the proportion of landed green turtles captured at Laguna Ojo de Liebre over the time period evaluated (Table 6; detailed description of data standardization in Supporting Information, Section 5). Due to the lack of documentation of turtle catch over this time period (O'Donnell, 1974), our estimate should be considered conservative.

For the Modern Fisheries Period, we used official *C. mydas* landing data for the late-20th century commercial fishery at Bahía de los Ángeles (Márquez cited in Seminoff et al., 2008), dating from 1962 to 1982. Landings were reported in metric tonnes and standardized to turtles per year. Landing data were not available for this period at Laguna Ojo de Liebre. Based on ethnographic data, we assumed that shipment volumes were representative of commercial captures and that all captures corresponded to *C. mydas*. We calculated the number of turtles shipped annually from the community to urban centres by developing the equation:

$$M_t = V_t K \tag{4}$$

where M_t is the number of turtles shipped annually (turtles per year), V_t is the approximate number of annual shipments (shipments per year) during year t, and K is the carrying capacity of the vehicles (turtles per shipment). K was a constant of 60 turtles and is the mode reported by sea turtle merchants and fishers. V_t was calculated from ethnographic data; we used parameters obtained from ethnographic data to adjust for seasonality in captures and changes in shipment frequency due to changes in infrastructure over time (all calculation procedures and parameter values are available in Supporting Information, Section 6, Equations S4–S6; Table S10).

3 | RESULTS

We estimate that sea turtle consumption remained stable between 1700 and 1950, before reaching an inflection point in the 1960s. Estimated annual captures over the 20-year period between 1960 and 1980, eclipsed the estimated annual captures of the previous 280 years by one order of magnitude in both locations.

3.1 | Pre-hispanic Period (1700–1750)

During the Pre-Hispanic Period, nomadic hunter-gatherers from the Yuman-Cochimí language family relied heavily on marine resources as a source of protein (Aschmann, 1959; King, 1997; Laylander, 2010), and sea turtles appear as a food source in the archaeological record since the earliest phases of human occupation, at least 12,000 years ago (Des Lauriers, 2006; Ritter, 2012). Stable isotope analysis and ethnohistoric data suggest that for Pre-Hispanic populations in the central desert of Baja California, sea turtles comprised 3% of animal protein consumed in inland regions, and as much as 14% of animal protein consumed in coastal areas (Aschmann, 1959; King, 1997). Marine turtles also appear in artwork and burials, suggesting symbolic or religious importance (Ritter, 1998, 2010a,b).

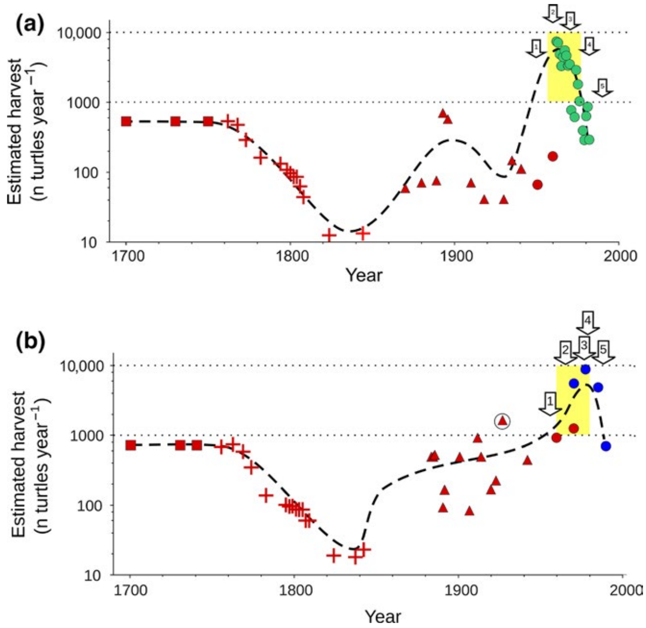

FIGURE 2 Estimated annual harvest of *C. mydas*, 1700–1990 from Bahía de los Ángeles (a) and Guerrero Negro/Laguna Ojo de Liebre (b) during the Pre-Hispanic Period (1700–1750; squares), Mission Period (1750–1850; crosses), Secular Period (1850–1945; triangles) and Modern Fisheries Period (circles). Consumption reconstruction data are in red (Equations 1 and 2), commercial reconstruction data are in blue (Equation 4), and official landing data are in green. Encircled values are outliers. The dashed line represents the suggested trend based on the rolling mean. Dotted lines indicate 10^3 order of magnitude, and the shaded area represents the intersection of years 1960–1980 and 10^3 order of magnitude catches. Arrow 1 indicates approximate dates of market formation. Arrow 2 indicates approximate dates of region-wide introduction of turtle nets, outboard motors, and fibreglass vessels. Arrow 3 indicates the opening of the Transpeninsular Highway (1974). Arrow 4 indicates the approximate beginning conservation efforts in the index beaches of Colola and Maruata, Michoacán (early 1980s). Arrow 5 indicates the total ban on sea turtle captures in Mexico (1990). [Colour figure can be viewed at wileyonlinelibrary.com]

Our earliest estimate of sea turtle consumption corresponds to two generations before the arrival of European missionaries (*c.* 1700), based on available paleonutritional and demographic data (Aschmann, 1959; King, 1997; Figure 2a,b). The lack of Pre-Hispanic demographic data from the central desert limits our ability to reconstruct sea turtle consumption before the early 18th century. However, it is likely that post-Pleistocene populations were small and widely dispersed, and within an order of magnitude of those recorded in early ethnohistoric documents (Laylander, 2010). Archaeological and ethnohistoric sources estimate a population of 4,000 people in the central desert—and around 12,000 in the entire peninsula—at the time of European contact between the late 17th and mid-18th century (Aschmann, 1959; Laylander, 2010; Rodríguez Tomp, 2002). We estimated annual consumption values of 535 and 740 turtles/year for Bahía de los Ángeles and Laguna Ojo de Liebre, respectively (Figure 2a,b; Table 4).

3.2 | Mission Period (1750–1850)

Jesuit, Dominican and Franciscan missionaries—envoys of the Spanish Crown—were the first Europeans to establish permanent settlement in Baja California, nearly 200 years after the Spanish conquest of the Aztec empire in mainland Mexico (Crosby, 1994; León Portilla, 2001). The Jesuits in particular were among the intellectual elite of their time—versed in philosophy, theology and natural sciences. As such, they left detailed accounts of the social life and natural surroundings of the missions, which had pragmatic value in the logic of Spanish imperial expansion (Crosby, 1994). The mission system was based on the forced sedentarization of the native hunter-gatherers which, coupled with disease and unfavourable conditions for agriculture, led to mass mortality of the indigenous peoples (Table 5). Within two generations of the founding of the missions of Santa Gertrudis and San Borja (Figure 1), the population of the central desert was reduced by 90% (Rodríguez Tomp, 2002), and Pre-Hispanic populations levels were not re-established until the mid-20th century (Early Capistrán, 2014b). Detailed baptismal and census records from the missions of San Borja and Santa Gertrudis allowed us to estimate demographic change and sea turtle consumption. During this period, the massive loss of human life reduced sea turtle harvests to levels lower than those of the Pre-Hispanic Period, and reduced pressure on sea turtle populations for an extended period of time (Figure 2a,b; Supporting Information, Section 3.2.1, Equation S2).

While colonization and agriculture would have caused important dietary shifts marked by increased consumption of plant foods, this period was characterized by famine, and dietary patterns responded largely to the availability of food sources, sea turtles being chief among them (Baegert, 1761/1982). In the context of mass human mortality, we consider that the effect of contingent dietary shifts over this period would not have been significant for calculations. However, we recognize that our estimates for this period may be high, as sea turtle consumption may have been reduced as a result of sedentarization.

Taxonomic distinctions between sea turtle species in this period were blurry. Categories used by Jesuits and Spanish naturalists overlap with the three taxa defined by mediaeval naturalists: the hawksbill (*E. imbricata*) and leatherback (*D. coriacea*) were recognized as distinct species, and all others were grouped within a single category (del Barco, 1757/1988; Longinos Martínez, 1787/1994; Rondeletti, 1554). However, we assumed that the bulk of sea turtle consumption consisted of green turtles, as this species is and was the most common at the study sites (Koch, 2013; López-Castro, Koch, Mariscal-Loza, & Nichols, 2010) and is considered the most desirable by modern-day local populations (Early Capistrán, 2014a,b; Mancini & Koch, 2009). Estimated annual consumption ranged from 8 to 757 turtles/year, and median harvest values for this period were 390 and 93 turtles/year in Bahía de los Ángeles and Laguna Ojo de Liebre, respectively (Figure 2a,b; Table 4).

3.3 | Secular Period (1850–1945)

After Mexican independence, the secularization of mission lands in Baja California led to large-scale commercial concessions to private, mostly foreign, companies (León Portilla & Piñera Ramírez, 2011; Romero Gil, Heath, & Rivas Hernández, 2003; Table 5). The region was integrated into global capitalism, through an extractive economy tied to the international demand for commodities like whale oil, gold and seafood (Henderson, 1972); however, few permanent settlements were established and population levels remained low for much of this period as a result of demographic collapse during the Mission Period (Henderson, 1972; León Portilla & Piñera Ramírez, 2011). Historical records such as whaling logs, mining reports, scientific reports and census data allowed for a detailed reconstruction of sea turtle harvests during this period. While sea turtles were caught commercially during this period, average annual capture remained within an order of magnitude of the previous century with the exception of two outlying years (1919 and 1925) in which a mining population boom and a short-lived commercial enterprise caused very brief increases in capture.

On the Pacific coast, whales, guano, seals, otters and salt were exploited intermittently by American and Russian fleets (Henderson, 1972; Vernon, 2009). In 1857, whaler Charles Scammon was the first navigator to breach the grey whale (*Eschrichtius robustus*) breeding grounds at Laguna Ojo de Liebre (known in English as Scammon's Lagoon). From 1858 to 1873, whalers flocked to the previously untouched whaling grounds (Henderson, 1972). While sea turtles were not the main target species, they were captured opportunistically for subsistence and commerce (Drew et al., 2016), and green turtles from Laguna Ojo de Liebre and the Pacific coast of Baja California were sold at luxury restaurants in San Francisco and as far away as Chicago (Daily Alta California 1860, 1871; O'Donnell, 1974). Green turtles, in particular, were considered a delicacy in the United States and Britain, and had been exploited commercially in the Caribbean since the 1700s for sale in cities like Boston, New York, and London (Anson, 1748; Jackson et al., 2001; McClenachan et al., 2006). Due to the opportunistic nature of turtle capture, harvest was highly variable. However, given the intermittent and short-lived whaling activity—which ended in <20 years as grey whale populations collapsed—we estimate that overall catch by whalers was relatively low: the estimated median value for annual commercial harvest from Laguna Ojo de Liebre during this period was 43 turtles/year (Table 6).

The California gold rush drew attention to Baja California, and in the late 19th and early 20th century, gold, silver and copper mines were tapped by American, British and Mexican investors (Goldbaum, 1918/1971; Romero Gil et al., 2003). Mining led to massive demographic shifts through a "boom and bust" economy, in which cities were established around veins and abandoned as mineral resources dwindled (Early Capistrán, 2014b; Romero Gil et al., 2003). Sea turtles were an important source of protein in mining communities, mainly in the form of salted meat and jerky. This processing method used only fillet meat, which lost up to 80% of its volume due to processing. Additionally, in contrast with fresh turtle consumption, edible organs and most fats were discarded. This processing pattern led to increased local consumption compared to previous years, which is particularly noticeable in 1925, when the mining towns of El Arco and Calmallí reached a peak population of ~1,000 residents (Figure 2a,b; Table 4).

Between World Wars I and II, sea turtles were fished commercially for export to California, USA, from the Pacific Coast of Baja California in years 1917–1923 and 1927–1932 (Averett, 1920; Nelson, 1922). As mining and railroad fortunes accumulated in California, investors tried their hand at importing East Pacific green turtles to high-end restaurants in San Francisco and San Diego. Large investments were made, including a canning facility in San Diego. This enterprise ran at full capacity from 1919 to 1921, when the schooner *Catarina* shipped up to 1,000 turtles a month from Laguna Ojo de Liebre during peak seasons (Averett, 1920; Karmelich, 1935; Nelson, 1922; Table 6). The magnitude of captures generated by this venture briefly raised concerns about the future viability of the fishery (Nelson, 1922; O'Donnell, 1974). However, the schooner shipments to San Diego ended in the early 1920s, presumably due to a lack of market demand in California, and as a result landings were reduced substantially (Karmelich, 1935; O'Donnell, 1974).

By the 1930s, turtle landings in California were limited to "one or two boats" that occasionally made shipments to San Diego, "but these are so spasmodic that a constant market cannot be maintained, with the result that the fishermen find it difficult to dispose of their catches whether large or small" (Karmelich, 1935). An account from 1931 describes the landing of 50 green turtles from Scammon's Lagoon at San Diego, on board the fishing boat "Vigilant." For 20 days, the crew "strove valiantly to dispose of the fare," but eventually 41 of the 50 turtles were shipped back to Mexico for lack of buyers, two were sold to "select dining resorts" in San Diego, and the rest were "butchered on board and retailed from the deck to Mexicans who came down for a piece of their favourite seafood" (The West Coast Fisheries 1931). The venture was described as "a failure, financially, and will not be repeated" (The West Coast Fisheries 1931). This is consistent with a reduction of sea turtle consumption in the United States towards the mid-20th century (Freedman, 2007). With the exception of the outlying year 1919, when ~2,686 turtles from Laguna Ojo de Liebre were imported to California, we estimate that annual commercial harvest in the early 20th century remained within an order of magnitude of captures in the past centuries (Table 6).

Local subsistence captures were carried out with harpoons, from wooden vessels powered by oars or paddles. Several factors limited fishing efficiency: the harpooners' ability (skill limited the number of turtles potentially caught per trip); weather, tides and lunar phases (their status limited the days when harpooning was viable: ideal conditions required calm seas and winds on a neap-tide, and moderate moonlight); propulsion (which determined trip duration and spatial extent of fishing); navigational knowledge and experience (which was based on triangulation, dead-reckoning, and celestial observations with limited instruments and required great expertise); and vessel capacity (open wooden vessels held no more than 20 turtles).

Additionally, commercial capacity was inhibited due to a limited market access because of (i) the isolation of the fishing sites (there were no urban population centres within 500 km); and (ii) lack of transportation and communications infrastructure including roads and telephones, respectively. In coastal communities, capture was limited to what could be used, and practically, none of the turtle was wasted: meat, offal, and blood were all consumed, and even the carapace could be boiled down to a gelatinous consistency and eaten, while oil was rendered for cooking and medicinal purposes. Bones were boiled in broth and then given to domestic dogs. The head and skin were the only by-products not considered fit for human ingestion and were left out for dogs and coyotes. Consumption patterns with minimal waste continued to be the norm in fishing communities throughout the 20th century. Sea turtle consumption ranged from 1 to 1682 turtles/year, with the maximum value corresponding to the year 1925. Median harvest values for local consumption were 71 turtles/year in Bahía de los Ángeles and 505 and in Laguna Ojo de Liebre (Figure 2a,b; Tables 4, 6).

Chelonia mydas nests mainly on tropical beaches, and nesting activity in the warm-temperate study area is rare (Koch, 2013; Seminoff, 2004). As a result, eggs were not traditionally consumed, and only 9% of fishers recalled having tasted sea turtle eggs at some point. Additionally, areas surrounding key nesting beaches in the Mexican Pacific were geographically isolated and sparsely populated until the second half of the 20th century. For example, there were no permanent human settlements near the most important green turtle nesting beaches of Colola nor Maruata, in Michoacán, until the 1950s, and egg harvests at these key nesting beaches were minimal (Alvarado & Figueroa, 1992; Clifton et al., 1995; Márquez, 1996).

3.4 | Modern Fisheries Period (1945–1990)

Urban growth along the Mexico-U.S. border increased demand for sea turtle products: from 1940 to 1970, the population of the state of Baja California increased by 1100%, mostly in cities along the Mexico-U.S. border such as Tijuana, Ensenada and Mexicali (Instituto Nacional de Estadística, Geografía e Informática 2015), which became the main markets for green turtle products (Figures 1 and 3). Fishing and commercial capacity grew thanks to new technologies: gillnets eliminated the need for skilled harpooners, increasing catch efficiency; fibreglass vessels boosted carrying capacity to 30 or more turtles per boat; and outboard motors greatly increased the spatial and temporal extent of fishing. The Transpeninsular Highway, inaugurated in 1974, shortened the trip to the Mexico-U.S. border from 2 weeks to 2 days, greatly increasing market access (Early Capistrán, 2014b).

Harvest peaked in the late 1960s and early 1970s, as estimated annual catches exceeded those the past 250 years by an order of magnitude (Figure 2a,b). During this period, we estimate that the median harvest value for local consumption at Bahía de los Ángeles was 282 turtles/year, compared to a median commercial harvest of 2,370 turtles/year. At Laguna Ojo de Liebre, the median harvest value for local consumption was 922 turtles/year, in contrast with a median commercial harvest of 5,220 turtles/year (Figure 2a,b; Table 4).

Unregulated harvests led to swift declines in green turtle abundance in the Eastern Pacific, reflected in nesting data and descriptions of population levels. Gravid females were captured in the fishery and, simultaneously, settlements and roads were built around key nesting beaches in Michoacán that had previously been unpopulated or harvested at subsistence levels (Clifton et al., 1995; Márquez, 1996). During the 1960s and 1970s, close to 100% of eggs were harvested

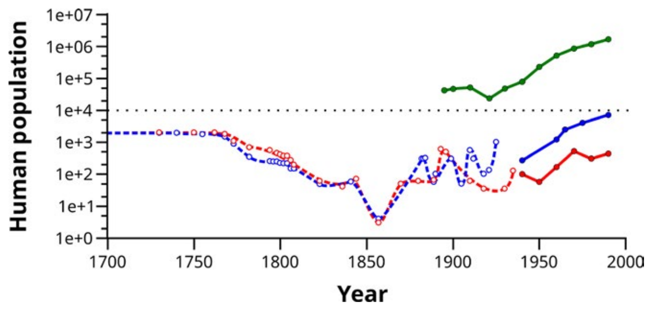

FIGURE 3 Approximate human population trends from 1700 to 1990: Bahía de los Ángeles (red), Laguna Ojo de Liebre (blue) and the Territory of Baja California Norte/State of Baja California (green). Open circles and dashed lines represent population levels reconstructed from historical and ethnographic data (n = 57). Solid circles and lines indicate census and intercensal data at 5 to 10-year intervals (n = 23; Instituto Nacional de Estadística, Geografía e Informática 2015, 2017a,b). [Colour figure can be viewed at wileyonlinelibrary.com]

until index beaches were protected in 1980 (Clifton et al., 1995; Márquez, 1996). While further information on recruitment patterns and stock composition is needed to directly evaluate the impact of egg harvest on *C. mydas* populations in the study area (Bjorndal & Bolten, 2008; Casale & Heppell, 2016; Koch, 2013), this process undoubtedly contributed to declines in abundance.

State intervention increased throughout the 1970s through licence restrictions, seasonal bans, nesting beach protection and re-population programs (Early Capistrán, 2010; Márquez, 1996; Seminoff et al., 2008). Unfortunately, these efforts came too late: the commercial green turtle fishery collapsed in the early 1980s (Figure 2a,b; Seminoff et al., 2008). A nominal ban on captures of *C. mydas* in 1983 was followed by a total ban on sea turtle captures in 1990, which remains in effect today (Márquez, 1996; Secretaría de Medio Ambiente y Recursos Naturales 2010).

4 | DISCUSSION

We quantified green turtle consumption and commercial harvest in the central desert of Baja California from 1700 to 1990 through the systematic use of non-traditional data such as ethnography and archives. We found that estimated annual catches in the 20-year period between 1960 and 1980 exceeded those of the previous centuries by an order of magnitude. This led to the collapse of the local green sea turtle population and, in consequence, of the fishery (Seminoff et al., 2008). While estimating historical green turtle population levels is beyond the scope of this study due to the species' complex life history and migratory patterns, we consider human impact to be an indicator of important shifts in abundance levels.

When all sea turtle captures were banned in 1990, the population had been greatly diminished: Caldwell (1963) reported 500 green turtles landed over just 3 weeks in Bahía de los Ángeles in 1962, but fewer than 200 turtles were landed from 1981 to 1985, and just over 300 were observed during the first 10 years of scientific monitoring between 1994 and 2004 (Seminoff, 2010; Seminoff et al., 2008). Although this simple comparison does not account for the large differences in fishing effort between the periods, it is clear that green turtle populations had been severely depleted by the time monitoring efforts began (Seminoff et al., 2008). Meanwhile, nesting at index shorelines plummeted. For example, at Colola beach in Michoacán nesting dropped from ~15,000 nesting females per year in the 1960s and early 1970s to around 200 nesting females per year in the late 1980s (Alvarado Díaz et al., 2001; Clifton et al., 1995; Delgado-Trejo, 2016).

Our reconstruction suggests that, at the two locations in the study area, sea turtle harvest remained relatively small and stable from 1700 to around 1950. Although we cannot quantify harvests further back in time, it is likely that hunter-gatherer populations in the peninsula remained within an order of magnitude of variation from the Early Holocene onward (Laylander, 2010), suggesting that the late 20th century fishery may have eclipsed thousands of years of captures. This is supported by reports of large captures along the coasts of Baja California in the 19th century and well into the 20th century. For example, in 1889 the steamer *Albatross* reported "a very remarkable catch" of 162 green turtles in a single haul of a 600 foot long seine in Bahía Tortugas, ~75 km southwest of Laguna Ojo de Liebre on the Pacific Coast (Townsend, 1916). In 1920, Averett reported a catch of 350 green turtles over 3 days in Laguna Ojo de Liebre (Averett, 1920). In Bahía de los Ángeles, several fishers reported occasional high captures limited only by their vessel's carrying capacity. One fisher remembered his crew filling a seven-tonne capacity boat with ~120 green turtles in just one night, using a single 40 fathom net, in 1960.

Until the 1960s, sea turtle fisheries around Mexico were almost exclusively dedicated to subsistence captures (Márquez, 1996). Additionally, areas surrounding key nesting beaches along the Mexican Pacific were geographically isolated and sparsely populated until the second half of the 20th century (Alvarado & Figueroa, 1992; Clifton et al., 1995; Márquez, 1996). These conditions restricted direct captures and egg harvests to subsistence levels, and it is likely that region-wide anthropogenic impacts were also limited until this time. Therefore, the oldest commercial fishers may have observed a level of abundance within an order of magnitude of Pre-Hispanic times. While calculating historical population levels is beyond the scope of this study, future research could build on these methods to estimate past abundance in this time frame, around the 1950s and early 1960s, in order to obtain references of historical baseline abundance.

4.1 | Subsistence vs. market economy

Estimated annual sea turtle capture increased by an order of magnitude due to demographic and economic shifts, both at regional and international scales. Furthermore, technologies such as gillnets, outboard motors and fibreglass vessels increased fishing efficiency. Additionally, improved infrastructure increased market access. From 1940 to 1970, the population of cities along the Mexico-U.S. border grew almost exponentially (Figure 3; Instituto Nacional de Estadística, Geografía e Informática 2015). Border cities became the main markets for green turtle products (Figure 1), and sea turtle restaurants and stands—known locally as *caguamerías*—were regularly supplied with green turtles from the central peninsula. *Caguamerías* became immensely popular, to the degree that tacos and other street foods are today in Mexico. This unregulated market led to a fast decline in sea turtle populations, in contrast with the local subsistence captures which had been limited by small human populations and minimal waste and had proved sustainable over long time spans.

The pattern of marine resource depletion as a result of national and international market dynamics has been repeated worldwide since the early days of capitalism (Langton, 2003; Roman & Palumbi, 2003; Schwerdtner Máñez et al., 2014). This has also been the case with sea turtle fisheries in other locations in Mexico, as well as the Caribbean, where captures were mainly for non-local luxury markets (Costa-Neto & Márques, 2000; Early Capistrán, 2010, 2014c; Nietschmann, 1974). Cinner et al. (2016) showed that market gravity—a metric of potential interaction with urban centres or markets measured in terms of the relative size of markets and their distance from fishing communities—is the strongest predictor of reef fish biomass loss: more so than population pressure, environmental conditions or national socio-economic context. Similarly, a strong correlation has been found between the demand for megavertebrates in international luxury markets and extinction risk (McClenachan, Cooper, & Dulvy, 2016). Furthermore, McClenachan and Kittinger (2012) found that contrasting social and historical trajectories greatly affect the long-term sustainability of fisheries, and that high economic connectivity and human population density, coupled with a lack of customary management systems, caused rapid overexploitation of marine resources.

We suggest that market forces were the main driver of the green turtle fishery collapse in the temperate feeding areas of Baja California. Decline was not caused by local subsistence fishing, but by a combination of (i) unprecedented and unregulated demand from urban centres; and (ii) resulting supply in the form of increased sea turtles capture made possible by improved fishing efficiency and market access. Demand increased in response to demographic and economic growth along the Mexico-U.S. border. Simultaneously, supply increased as technologies such as gillnets and outboard motors improved fishing efficiency and improved infrastructure increased market access.

4.2 | Turtles in time

In broad terms, human impacts on large marine vertebrate populations have shown a similar pattern worldwide: slow changes over millennia, rapid depletion in recent centuries, and accelerated decline in the 20th century (Jackson et al., 2001; Lotze & Worm, 2009). For example, Caribbean green sea turtle populations were decimated by large-scale commercial fisheries for export to Europe as early as the 18th century (Bjorndal & Jackson, 2003; McClenachan et al., 2006). This was due greatly to the Caribbean region's fast integration into the global economy, and relative proximity to European markets with important demands for sea turtle products (Nietschmann, 1974). According to sea turtle expert Archie Carr, "more than any other dietary factor, the green turtle supported the opening of the Caribbean" (Carr cited in Nietschmann, 1974). Remnant populations were exploited throughout the 20th century, and technologies such as nets and outboard motors permitted more efficient captures and accelerated their decline (Nietschmann, 1974).

The central desert of Baja California presents a different trajectory: we suggest that the turning point in human impact was much more recent, in the 1960s, when estimated annual captures exceeded those of the previous centuries—including late phases of Pre-Hispanic occupation—by an order of magnitude. We consider that colonization processes, economic cycles and geographic isolation had important roles in this unique scenario. First, as the American continent was colonized by Europeans, in broad terms, from east to west and south to north (in the case of the Northern Hemisphere), Baja California was colonized centuries later than the Caribbean islands or mainland Mexico: Jesuit missionaries did not establish permanent settlements in the peninsula until nearly 200 after the fall of the Aztec empire (Crosby, 1994; León Portilla, 2001). By the time colonial presence was first established in the peninsula, much of Latin America and the Caribbean were thoroughly integrated into a global economy; however, due to the adverse conditions in the desert peninsula and its geographic isolation from the colonial metropolis, trade to and from the peninsula in general, and the central desert in particular, was scarce during the 18th and early 19th centuries (Baegert, 1761/1982; Crosby, 1994; León Portilla, 2001; Linck & Burrus, 1967).

From the 1850s until the 1950s, an extractive economy based on mining, whaling and fishing had important impacts on the region (Henderson, 1972; Piñera Ramírez, 1991). However, the lack of a constant market for sea turtle products in urban centres and the small local populations kept impacts on sea turtles mostly within an order of magnitude of past centuries. This is supported by reports of very high abundance from the late 19th century until the early 1960s (Averett, 1920; Caldwell, 1963; Townsend, 1916). It was not until the 1960s that a confluence of factors—market demand in new and accessible urban centres coupled with increased infrastructure and catch efficiency—led to swift declines.

We do not wish to imply that a "pristine" baseline exists at any point in the chronology. Long-term abundance of resource species has been affected both by human activity and long-term climate fluctuations (Lotze & Worm, 2009), to the degree that any point chosen as a baseline is, to some extent, arbitrary. Furthermore, the idea of the "New World" as a pristine wilderness before the arrival of Columbus is both scientifically unsupportable and embedded in colonial discourse (Denevan, 1992; Kay & Simmons, 2002). Beyond the vast empires of Mesoamerica and the Andes, hunter-gatherers—such as the Pre-Hispanic inhabitants of Baja California—had significant impact on coastal and marine ecosystems centuries before written records exist (Rick & Erlandson, 2009). Archaeological evidence, such as large shell middens, suggests that pre-historic human activity had significant impact on Baja California's marine ecosystems (Des Lauriers, 2011; Laylander, 2010). However, currently archaeological data are insufficient to reliably calculate human impacts on sea turtle populations in early phases of human occupation. In this context, we have chosen to extend our reconstruction as far as sources allow us to do so reliably in order to show processes of change over the longest time span possible.

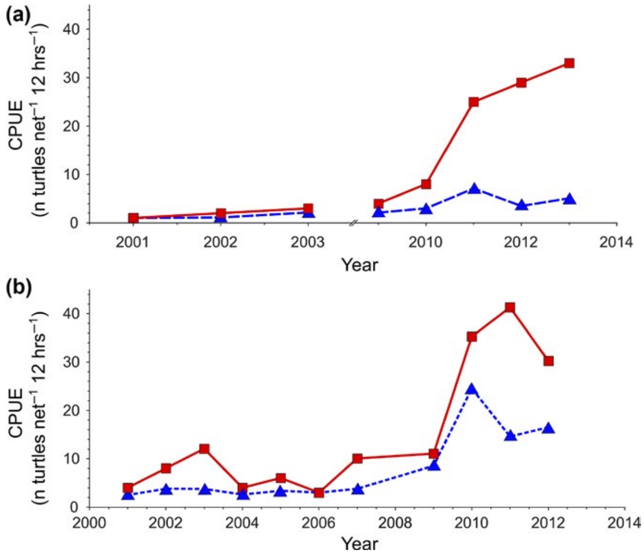

FIGURE 4 Catch Per Unit Effort (CPUE) of green turtles in scientific in-water monitoring in Bahía de los Ángeles (a) and Guerrero Negro/Laguna Ojo de Liebre (b). CPUE is defined as the number of turtles caught by one 100x8*m* net in 12 hr. Maximum CPUE values in a given year (red) are labelled with a rectangle and connected with a solid line. Mean CPUE values for a given year (blue) are labelled with a triangle and connected with a dotted line. Data from Comisión Nacional de Áreas Naturales Protegidas and Grupo Tortuguero de las Californias A.C. [Colour figure can be viewed at wileyonlinelibrary.com]

4.3 | Past and present

Green turtle catch rates in scientific monitoring conditions have increased since the early 2000s (Figure 4a,b; Comisión Nacional de Áreas Naturales Protegidas, unpublished data; Grupo Tortuguero de las Californias A.C., unpublished data; Koch, 2013; López-Castro et al., 2010). Populations at nesting beaches have also increased since the early 2000s, with marked increases from 2010 onward (Figure 4; Delgado-Trejo & Alvarado Díaz, 2012; Delgado-Trejo, 2016). This 25- to 30-year time frame corresponds roughly with the approximate generation length of East Pacific green turtles (Seminoff, 2004). These increases have been attributed to a combination of initiatives, including the total ban on sea turtle captures in 1990, along with nesting beach protection since 1980 (Márquez, 1996) and increased involvement of governmental, academic and non-governmental institutions in sea turtle conservation (Koch, 2013; Delgado-Trejo, 2016; Figure 5).

The pattern of collapse in the later years of the fisheries in the 1980s and the increase in the past 10 years are congruent with fishers' perception of changes in abundance (Figure 6). As part of a series of recurring questions, fishers were asked if there were "many fewer," "somewhat fewer," "about the same," "more," or "many more" green turtles present today as in the years they worked in the commercial green turtle fishery (Sáenz-Arroyo, Roberts, Torre, & Cariño-Olvera, 2005; Sáenz-Arroyo, Roberts, Torre, Cariño-Olvera, & Enriquez-Andrade, 2005; Supporting Information, Section 1.3, Table S2). We recognize the inherent limitations of these data, and present them only as an initial exploration of possible tendencies; 59% of fishers aged 40–64 (n = 10) and 36% of fishers 65–89 (n = 5) responded "much more." This suggests a shifting baseline between younger and older fishers (Pauly, 1995; Sáenz-Arroyo, Roberts, Torre, & Cariño-Olvera, 2005). However, the data also suggest a positive overall outlook: none of the fishers considered that there were "many fewer" turtles at present, and all fishers who responded "somewhat fewer" (16%, n = 5) added that green turtles are currently abundant, but below the level of their years in the fishery.

Perceived changes in abundance among older fishers are particularly interesting, as our reconstructions suggest an inflection in long-term abundance in the 1960s. Since older fishers worked in the early years of the commercial fishery—and in some cases as subsistence fishermen in the 1940s and 1950s—they witnessed what could be considered a historical baseline abundance level for these two locations. These observations are vital for future evaluations of conservation status, and carrying out this type of research while older expert fishers are alive is of prime importance (Johannes et al., 2000; Sadovy & Cheung, 2004; Sáenz-Arroyo, Roberts, Torre, & Cariño-Olvera, 2005).

Evaluating current and present turtle population levels, conservation status, or recovery is beyond the scope of this study. However, our methods could be used to generate reliable baseline abundance data with which to compare current abundance levels. Further research, in the form of standardized Catch Per Unit Effort (CPUE) comparable to modern monitoring data, is needed to evaluate past and current local abundance in terms of biomass. Additionally, long-term analysis of changes at nesting beaches and changes in population structure

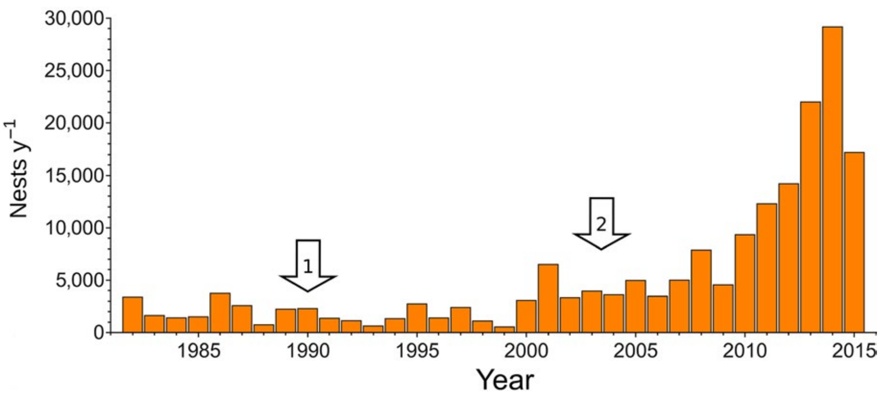

FIGURE 5 Annual green sea turtles nests at Colola, Michoacán (Delgado-Trejo, 2016). Adapted from Delgado-Trejo (2016). Arrow 1 indicates the total ban on sea turtle captures in Mexico (1990). Arrow 2 indicates approximate dates for the start of monitoring efforts at the study sites (early 2000s). [Colour figure can be viewed at wileyonlinelibrary.com]

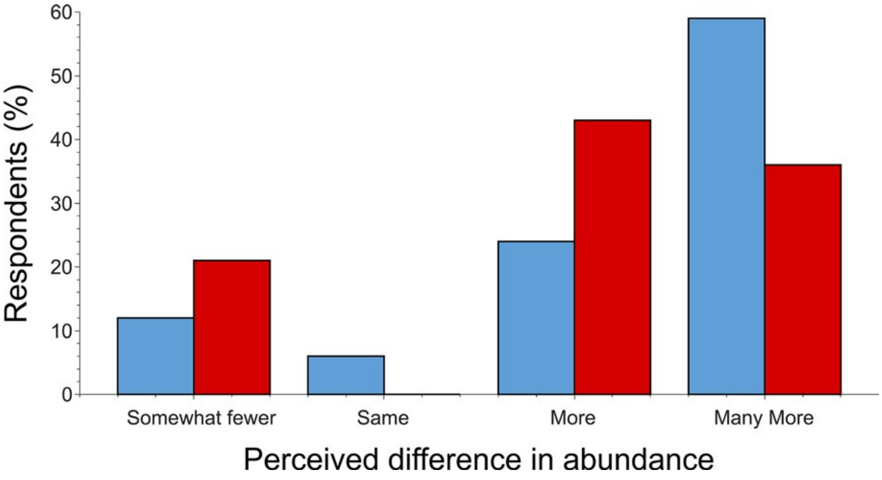

FIGURE 6 Fishers' perception of differences in green sea turtle abundance between the present and the years in which they caught green turtles commercially (both communities). Red bars represent fishers aged 65–89 (n = 14), and blue bars represent fishers aged 40–64 (n = 17). [Colour figure can be viewed at wileyonlinelibrary.com]

are required to evaluate changes at species or regional levels (Casale & Heppell, 2016; Kittinger et al., 2013; McClenachan et al., 2006). Although we cannot evaluate the degree of recovery at present, recent increases provide a positive outlook for this green turtle population, and speak to the success of conservation efforts in feeding and nesting areas. (For interpretation of the references to colour in this figure, please refer to the web version of this article).

4.4 | Implications for management

The recent green turtle population increase in Baja California echoes increasing population trends in various *C. mydas* stocks in the Central Pacific and West Atlantic (Balazs & Chaloupka, 2004; Broderick et al., 2006; Chaloupka & Balazs, 2007; Chaloupka et al., 2008). This shows that relatively simple, widespread conservation efforts, such as protection from human hazards—for example, unregulated fishing and egg harvests—can have a profound impact on population levels of once-depleted green turtle stocks (Chaloupka et al., 2008). Nonetheless, green turtles continue to face threats such as by-catch, poaching, habitat degradation, and climate change (Koch, Nichols, Peckham, & de la Toba, 2006; Mancini & Koch, 2009; Mancini et al., 2011; Seminoff, 2004).

Sound management decisions require solid recovery targets based on reliable information. With organisms subjected to long-term exploitation, we risk underestimating the degree of change by limiting decision-making to recent experimental data (McClenachan et al., 2012; Pauly, 1995; Sáenz-Arroyo, Roberts, Torre, & Cariño-Olvera, 2005; Sáenz-Arroyo, Roberts, Torre, Cariño-Olvera, & Enriquez-Andrade, 2005). Through our reconstruction of past harvests, we are confident that we have determined a point in time, between 1950 and 1960, that can serve as a temporal reference point before large-scale exploitation which can be used in the future to establish baseline abundance and recovery targets by building upon our methods.

4.5 | Integrating local and scientific knowledge

This type of research is only possible through the construction of collaborative knowledge between scientists and local experts. A critical approach to non-traditional data sources should not be confused with invalidating the credibility of place-based empirical knowledge, which is based on experiential information accrued over generations, with its own particular epistemologies (Beaudreau & Levin, 2014; Idrobo & Berkes, 2012; Mistry & Berardi, 2016). Invalidating such knowledge without attempting to confront epistemological differences risks creating value judgements embedded in forms of colonial representation (Mistry & Berardi, 2016; Sáenz-Arroyo & Revollo-Fernández, 2016). Rather than seeing place-based empirical knowledge as subjective and arbitrary—in contrast with the perception of science as objective and rigorous—we must make a concerted effort to bridge epistemological gaps, recognizing that all forms of knowledge are value-laden and produced by socially situated actors (Mistry & Berardi, 2016). This dialogue between science and place-based empirical knowledge is of prime importance not only to understanding past ecosystem conditions, but also to facing current and future global challenges such as ecosystem degradation and climate change (Klenk & Meehan, 2015; Mistry & Berardi, 2016).

We must highlight the importance of recognizing and integrating fishers' knowledge as a way of decolonizing conservation. Implementing conservation policies and ideologies based on politically and economically dominant agendas further marginalizes the communities most affected by natural resource depletion, and can potentially cause them great harm (Adams & Mulligan, 2003; Langton, 2003; Mistry & Berardi, 2016). Instead, scientists must take a self-critical and collaborative approach which considers the way people perceive, allocate, and manage their natural resources (Costa-Neto & Márques, 2000; Johannes, 1993; Mistry & Berardi, 2016). When approaching conservation issues, scientists should first engage with the communities that interact closely with the natural environment, rely on it directly for their livelihood most, and are most affected by environmental degradation (Mistry & Berardi, 2016). This also implies respectfully acknowledging and understanding each community's distinctiveness and epistemology—as well as the rules, values, ethics and ways of knowing related to resource use—providing relevant scientific knowledge, and establishing self-determination as a key principle of engagement (Johannes, 1981, 1993; Mistry & Berardi, 2016; Weiss, Hamann, & Marsh, 2012).

4.6 | Methodological and epistemological challenges

The use of non-traditional data for population ecology—such as place-based empirical knowledge and the historical record—requires a systematic approach based on tried methods from the social sciences (Baisre, 2016; Taylor, 2013). It requires engagement with communities and sources—placing fisheries and fishing societies in a historical, social, cultural and economic context—rather than approaching contributors and documents as mere sources for numerical data extraction (Anderson, 2006; Bolster, 2006; Harrison, 1997; Mistry & Berardi, 2016). In this sense, participation of trained social scientists is fundamental.

The epistemological challenges of integrating both historical and place-based empirical knowledge into population ecology deserve particular attention (Taylor, 2013). Bridging various modes of knowledge production requires an active engagement and dialogue with anthropology and the philosophy of science—as well as epistemology, phenomenology, hermeneutics and ethics (Alagona, Sandlos, & Wiersma, 2012; Cajete, 2004)—in close collaboration with social scientists and humanities scholars (Anderson, 2006; Bolster, 2006). In our case, this dialogue was facilitated by the inclusion of an anthropologist (M.M.E.C.) and a philosopher (G.G.M.) as part of an interdisciplinary research team. This type of constructive, multidisciplinary collaboration improves the reliability of results and contributes to solving broader theoretical issues.

4.7 | Concluding comments

Developing robust estimates of past marine animal exploitation requires a solid interdisciplinary framework along with collaborative knowledge-building with local experts. Through the use of ethnography and historiography, we were able to develop detailed estimates of past green sea turtle capture in a key region of Northwest Mexico. We found that from 1700 to around 1960, sea turtle capture remained within an order of magnitude except for two outlying years (1919 and 1925). During the Pre-Hispanic and Mission Periods, harvest levels changed primarily in response to human demographics and local consumption patterns. During the Secular Period (1850–1945), harvest was driven by global economic trends, such as whaling, mining, and early industrial fishing, but remained relatively low. Between 1960 and 1980, the growth of cities along the Mexico-U.S. border and the growing, unregulated demand for sea turtle products—coupled with increased fishing efficiency and infrastructure—led to overexploitation and green turtle population collapse. These 20 years of market demand led to the depletion of a fishery that had been of fundamental importance for millennia. While recent monitoring data suggest a positive outlook for this green turtle population, further research is needed to evaluate past and current turtle abundance, as well as to monitor conservation status.

Through this regional study, we have developed a methodological framework that can be applied widely to reconstruct past marine animal exploitation patterns in data-poor contexts. This methodology can be used to develop time series for other heavily exploited organisms and may help reconstruct and understand long-term change where ecological or fisheries data are unavailable. By incorporating methods from social sciences to solve the epistemological difficulties entailed by this type of research, we hope to contribute to the development of reliable approximations to the study of long-term change in the oceans. This dialogue between the natural and social sciences, place-based empirical knowledge and the humanities could prove vital for understanding both past environmental conditions and addressing current and future global challenges.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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