Biological Conservation 170 (2014) 20–27

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Historical commercial exploitation and the current status of Hawaiian green turtles

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ARTICLE INFO

Article history:
Received 21 September 2013
Received in revised form 8 November 2013
Accepted 10 November 2013

Keywords:
Historical ecology
Commercial fisheries
Wildlife harvests
Hunting
Ethnography

ABSTRACT

Biodiversity conservation is often limited by short-term records of abundance, geographic distribution, and population dynamics. Historical information can provide a context for assessing current population status and defining recovery, especially for populations recovering from chronic human overexploitation. Here we analyze three decades (1948–1974) of commercial landings from a green turtle fishery in the Hawaiian Islands. Artisanal and commercial overharvesting drove the population to its listing under the U.S. Endangered Species Act in 1978, but the population has since increased and its recovery is being debated. While this turtle fishery was small in scale – with a limited effort, productivity, and revenue – we find dramatic declines in catch per unit effort and a spatial progression that strongly suggest rapid local population depletion. Harvests initially targeted coastal areas near commercial markets but quickly shifted to exploit more remote areas, expanded effort, and increasingly relied on more extractive gears. Additional analyses of economic data, restaurant menus, and expert interviews indicate the fishery was driven by limited, local demand. The seemingly incommensurate scale of the fishery and its impacts reveal the Hawaiian green turtle population was already significantly depleted when commercial fishery began. We describe how historical studies can inform conservation management, including population assessments.

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1. Introduction

Marine ecosystems have been heavily exploited for millennia (Allen, 2007; Bjorndal and Jackson, 2003; Jackson et al., 2001; Lotze et al., 2006; McClenachan et al., 2006; Pandolfi et al., 2003; Rick and Erlandson, 2009). Historical research on human impacts to marine systems has proven critical for assessing their current status and defining recovery (Lotze et al., 2011; McClenachan et al., 2012; Pauly, 1995). For species such as sea turtles, historical research has become a recent interest (Allen, 2007; Bjorndal and Jackson, 2003; McClenachan et al., 2006; Witzell, 1994) but crucially it has not been incorporated into population assessments (Conant et al., 2009; NMFS 2007a,b). This gap limits understanding of the historical drivers for population declines and the benefits it might provide conservation planning. A recent comprehensive National Research Council review (Bjorndal et al., 2010) on sea turtle population assessments, for example, focused exclusively on modern survey data and its analysis. Though the NRC review provides helpful guidance on integrating demography and abundance, the issue is that such data – even if decades long – represent already-depleted populations (Kittinger et al., 2013). Modern surveys of such populations, even when analyzed with sophisticated quantitative models, are biased reference points (Pauly, 1995; Zu Ermgassen et al., 2012), which can lead to incomplete benchmarks for conservation management. Our present study aims to provide historical context for understanding modern scientific surveys and inform conservation efforts.

Recent studies (Kittinger et al., 2011, 2013; Van Houtan et al., 2012) show there are three distinct phases of sea turtle exploitation in Hawaii. The first during indigenous Polynesian societies (1250–1778), the second between European contact and World War II (1779–1945), and the final period until federal and state protections began (1946–1974). These periods comprise different threats at varying magnitudes, affecting different segments of the population across its geographic range. Archeological excavations, for example, indicate hunting pressure from indigenous Polynesians was widespread and probably extirpated important nesting areas in the Main Hawaiian Islands (Kittinger et al., 2013). In the 1800s, ships from Europe, North America, and Asia visiting the uninhabited Northwestern Hawaiian Islands (NWHI) frequently made large turtle harvests for subsistence and commercial trade

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0006-3207/$ - see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.biocon.2013.11.011

(Amerson, 1971; Elschner, 1915; Kittinger et al., 2011; Van Houtan et al., 2012). By 1900, green turtles (*Chelonia mydas*) were ubiquitous in Honolulu markets and restaurants, but by 1950 nesting was essentially extirpated everywhere except a single remote atoll. From 1946 to 1974, the territory and state of Hawaii licensed a commercial turtle fishery and kept detailed records of its operation. Since 1974, sea turtle harvests have been prohibited and the abundance of nesting green turtles at the population's major rookery has increased appreciably. This seeming success story has prompted debate about the nature of population recovery (Chaloupka and Balazs, 2007; Kittinger et al., 2013; Pilcher et al., 2012; Snover, 2008) and whether Hawaiian green turtles still need conservation protection (NOAA, 2012).

Here we examine landings data from this fishery to understand the role of commercial harvests in the historical depletion of green turtles. Such information on historical abundance or pressures is uncommon for protected species (Lotze et al., 2011; McClenachan et al., 2012), though it provides potentially valuable insights for assessing current population status and evaluating recovery. Our analyses first describe the spatiotemporal and demographic patterns of the fishery. Then we document the spatial expansion of the fishery across Hawaii and describe shifts in strategies to capture turtles. Because the fishery operated before standardized turtle surveys in Hawaii (Balazs, 1980), catch per unit effort (CPUE) may provide insights into population abundance (Myers and Worm, 2003; O'Donnell et al., 2012) during this period. Next we survey relevant economic and market trends, analyze restaurant menu data, and summarize findings from interviews with key fishery experts. As the fishery has been defunct for four decades, this latter step is an important supplement that provides critical context for our analyses of fishery data. This study is part of our larger effort (Kittinger et al., 2013; Van Houtan et al., 2012, 2013) to use historical research to inform modern sea turtle assessments and conservation planning in Hawaii and the Pacific Islands.

2. Methods

2.1. Fishery, economic, and interview data

Landings data from the Hawaiian green turtle fishery and GIS shapefiles of fishery statistical areas are provided by the U.S. National Marine Fisheries Service, Pacific Islands Fisheries Science Center, Fisheries Monitoring Branch and maintained by the State of Hawaii Department of Aquatic Resources (HDAR). Catch data comprise 635 trip reports from January 1948 to March 1974. Market prices from mainland U.S. turtle fisheries were reported previously (Witzell, 1994). Consumer Price Index (CPI) values that correct for inflation are from the U.S. Department of Labor, Bureau of Labor Statistics. From 1948 to 1963 we calculate the Honolulu CPI based on its linear relationship ($R = 0.99$) to the Los Angeles CPI from 1964 to 2009. Retail motor fuel prices (leaded gasoline) are from the U.S. Energy Information Administration, Annual Energy Reviews. Tourist visits to Hawaii are provided by the Hawaii Tourism Authority and Hawaii State Department of Business. Hawaii resident per capita income is from the U.S. Department of Treasury, Internal Revenue Service (Schmitt, 1977). Restaurant menus are sourced from: private collectors; the Harriet Thomas Collection at the Kapiolani Community College Library; the Hawaiian Studies Collection at the Hamilton Library, University of Hawaii; Bishop Museum archives; Los Angeles Public Library; New York Public Library; and the University of Nevada at Las Vegas Digital Collections (in order of prevalence). We obtained 427 menus, but eliminated those from cruise ships as we could not guarantee the local provenance of their pantry (Van Houtan et al., 2013).

Background information on turtle harvests was taken from relevant literature (Beckley, 1883; Bingham and Stokes, 1906; Bryan, 1915; Cobb, 1905; Fornander and Thrum, 1919; Titcomb, 1972) and from unstructured oral interviews. We interviewed 16 Hawaiian fishers, historians, community elders, retailers, and fishery managers. We used a chain referral or snowballing process (Bernard, 2011; Kvale, 1996) to identify respondents with knowledge of the history, operation, and economics of sea turtle harvests. Due to the time transpired since the fishery was active, few individuals with first-hand knowledge of the fishery are available, limiting the size of our respondent pool. Qualitative data from interviews was transcribed and observations were aggregated and used as contextual information in this study. Further, we employed verbal interviews, without any written survey or questionnaire, and we kept all respondents' personal identifying information anonymous. All research was in compliance with human subject regulation 45 CFR 46.101(b)(2) of the U.S. Department of Health and Human Services, Office for Human Research Protections, and best practices for social science research (Bickman and Rog, 2009).

2.2. Data analysis

We calculated annual turtle landings by mass and in numbers of turtles. When trip reports only list landing mass (32%, 206/635) we calculated individuals harvested from the modeled average turtle mass of that year's landings. As we expect no parametric form we fit locally-weighted regressions, or LOESS (Cleveland and Devlin, 1988), to annual summaries of each turtle landings series. We mapped the total landings (by mass) within each fishery statistical area. To understand fishing effort, we calculated the frequency of annual trips per boat license, and noticing a linear pattern on a log–log scale, fit power law models to the data. We calculated the frequency of landed turtles by mass and fit various probability distributions (Online Methods, Table S1) to the data using maximum likelihood techniques (Van Houtan et al., 2007) and ranked models with Akaike Information Criteria (AIC).

To detect for spatial expansion, we grouped fishery statistical areas by their immediate proximity to major urban markets, all other nearshore areas, and offshore zones. We computed the total annual area fished using ArcMap (ESRI, 2009) to calculate shapefile areas from the fishery statistical zone fished each trip and calculated the average mass of landed turtles separately for each spatial grouping. We calculated CPUE annually as the number of turtles landed divided by the cumulative fished area (the geographic area of each HDAR statistical unit fished for turtle, named on each trip report). We compared the proportion of landings from specialized turtle nets (known as *upena kolo*) to all other gears combined. We tabulated annual revenue for the fishery by subtracting fuel expenses from the gross earnings, adjusting for inflation to 2009 dollars. We determined fuel expenses by calculating the travel distances between the port of landing and zone fished, assuming a fuel efficiency of 5 km gal^{-1}. We report annual Hawaii tourist visits, resident per capita income, and use exponential models to describe their annual changes. To assess the how restaurants influenced fishery demand; we examined the occurrence of turtle on local restaurant menus (Van Houtan et al., 2013). We calculated its presence – and that of beef and local fish guilds – in a 9-year moving window. Further information on the restaurant menus is available elsewhere (Van Houtan et al., 2013).

3. Results

The official record for the commercial green turtle fishery in Hawaii spans 9567 days during which 2431 turtles were harvested – roughly one turtle taken every 4 days.

Landings data in Fig. 1a and b show the fishery was initially productive, drops steeply from 1957 to 1964, and then increased until the fishery closed in 1974. Peak production was 11.6 tonnes (t) in 1973 (Fig. 1b), but peak take (347 turtles) occurs in 1948, the first year (Fig. 1a). The frequency of boat trips per year decreases according to a power law ($R = 0.99$), suggesting that while most fishery operators made a few trips with landings annually, a small minority of operators repeatedly targeted turtles with success (Fig. 1c). Juvenile turtles were predominantly harvested (Fig. 1d) with the highest-ranked size class probability model being a heavy-tailed log-Sech distribution (Van Houtan et al., 2007). According to this model the most frequently taken turtle was 30.5 kg, which

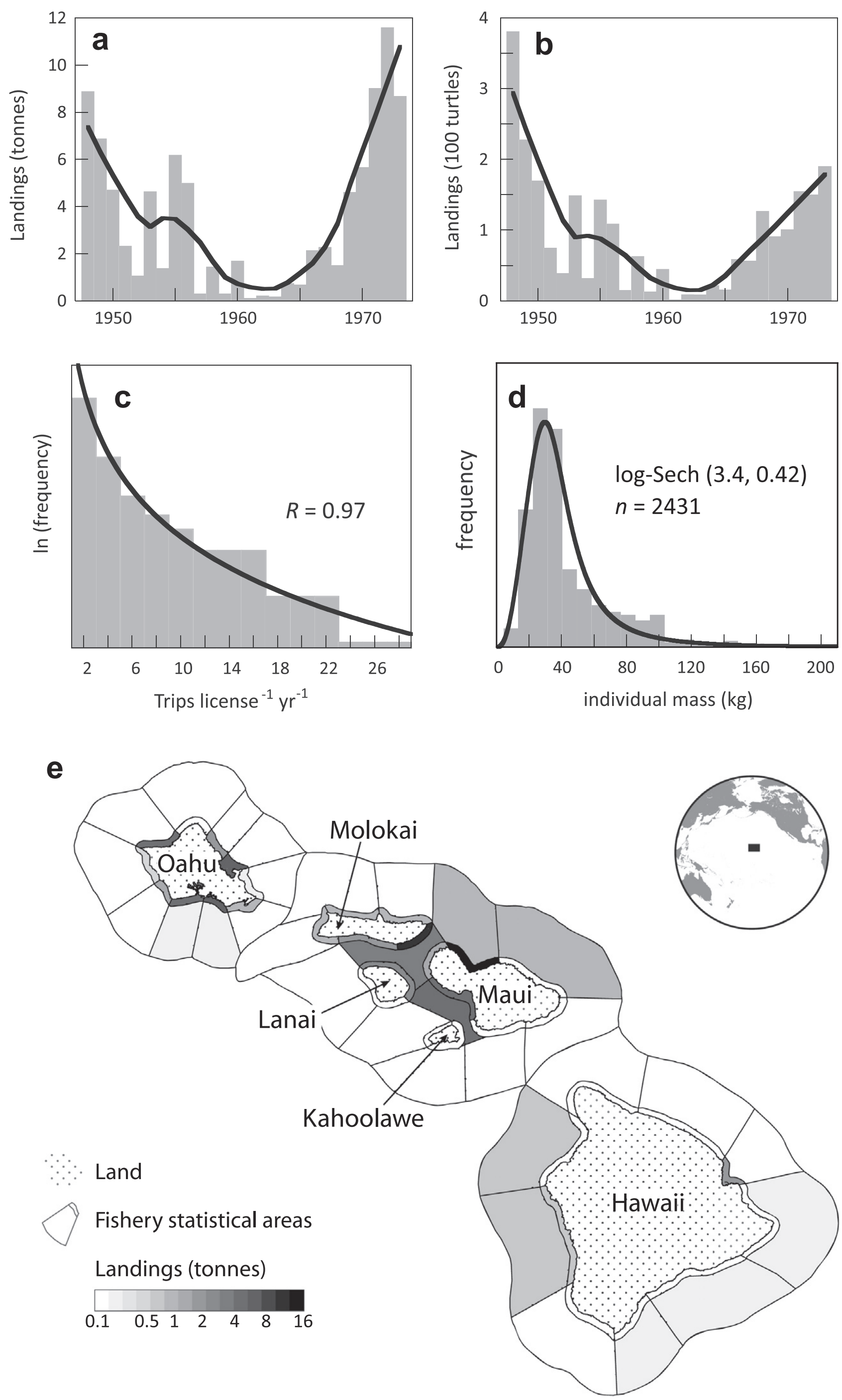

Fig. 1. Hawaii turtle fishery patterns, 1948–1974. Green turtle landings by (a) mass, and (b) individuals. Landings decline from the outset to 1960 and subsequently increase until the fishery closure. The fishery never exceeds 400 turtles yr^{-1} or 12 t yr^{-1}. Lines are locally-weighted regressions. (c) Individual boat effort was limited, with 86% of licensees making 6 or fewer trips per year. Fitted model is a power law. Landings and trip frequency indicate the fishery was a small-scale commercial operation with many operators. (d) Mostly juvenile turtles were harvested, as seen by the heavy-tailed probability model fit. Juveniles comprised 66% of harvests, subadults were 18%, and adults were 16%. (e) Measured by mass, 83% (76.9 t) of landings are concentrated in nearshore zones. Maui Nui (Maui, Molokai, Lanai, and Kahoolawe) collectively represents 57% (52.7 t) of the all landings, and 3 of top 5 individual fishery zones when ranked by mass. Kauai and the Northwestern Hawaiian Islands (not pictured) produce <7% (6.2 t) of landings. Shaded region in map inset indicates global position of the Hawaiian Archipelago. Polygons are the fishery statistical areas established by the State of Hawaii Department of Aquatic Resources (HDAR).

translates to a straight carapace length (SCL) of 63.8 cm based on the modeled relationship of SCL to mass ($y = 0.00015x^{2.935}$, $R = 0.96$, $n = 2168$) for Hawaiian green turtles. Considering size-age relationships (Balazs, 1980), this means the fishery most frequently harvested juveniles, consistent with market accounts from the early 1900s (Bryan, 1915). Fig. 1e shows landings are concentrated in Maui Nui (collectively Maui, Molokai, Lanai, and Kahoolawe) where 3 of the 5 most productive fishery zones are located. Fishers caught more turtles in nearshore than offshore zones, though offshore areas of Maui Nui were surprisingly productive. The shallow interisland land bridge unique to Maui Nui (Boland and Parrish, 2005) and extensive macroalgae beds there (Friedlander et al., 2008) may explain this.

The commercial sea turtle fishery was initially centered around the major market centers on each island (Honolulu, O'ahu; Kahului, Maui; and Hilo, Hawaii). By the early 1950s, however, fishery effort relocates to nearby coastal zones, and by 1968 effort is increasingly directed towards offshore areas (Fig. 2a). As a result, the total area fished from 1968 to 1974 alone is more than twice the area fished in the previous 20 years (Fig. S4). CPUE drops sharply – averaging 20% annual declines over the first five years – and continues decreasing throughout the period (Fig. 2b). After 1965, the average mass of turtles landed increases in all zone regions, but is always greater offshore (Fig. 2c). Turtles captured offshore were on average twice the mass of turtles landed nearshore before 1965. This demographic shift in landings accompanies an increasing reliance on specialized turtle nets to land turtles (Fig. 2d). Together, these data suggest a fishery that was constantly increasing effort and shifting tactics to meet diminishing returns (Fig. 2b).

Fig. 3a shows the market values for turtle meat in Hawaii exceed and outpace those from the U.S. Mainland, and that value increases as CPUE declines (Fig. 2b), suggesting rarity. Total fishery revenue declines annually from 1948 to 1965 and then spikes in 1971–1972 (Fig. 3b). Fishery revenues show that the fishery was a small-scale, artisanal operation, with relatively small economic returns. Even when adjusted for inflation to 2009 dollars the cumulative revenues over the 27-year span is \$345,000, averaging just under \$13,000 annually. Tourist visits to Hawaii (Fig. 3c) and local resident per capita income (Fig. 3d) increase exponentially ($R = 0.99$ for both) during the fishery period, aided by statehood and the advent of commercial jet service in 1959 (Allen, 2004; Schmitt, 1977).

Analysis of 371 Hawaii restaurant menus from 1928 to 1974 shows that green turtles were not common in Hawaiian restaurants during the time the fishery operated (Fig. 3e), contradicting previous speculation (Chaloupka and Balazs, 2007). On average, turtle appeared on 3% of menus (min = 0%, max = 5%) and was consistently uncommon. By comparison, frog legs (not plotted) were three times as popular as turtle (min = 3%, ave = 8%, max = 16%). Beef items were consistently popular (min = 75%, ave = 90%, max = 96%) with a slight decline during the World War II, most likely from rationing. Reef fish species appeared on every menu at the outset, but rapidly decline from 1935 to 1960, and are subsequently rare. Pelagic fish species are uncommon on menus from 1930 to 1945, and then steadily increase, corresponding with global expansion of pelagic fisheries after World War II (Pauly et al., 2002; Swartz et al., 2010). We report a more complete treatment of the menus elsewhere (Van Houtan et al., 2013).

The aggregate picture from our expert interviews is that the commercial turtle fishery in Hawaii was small in scale and catered primarily to small, local fish markets who sold turtle meat directly to local residents. A majority agreed turtle was only uncommonly sold in restaurants (11/16, 69%) though a few (4/16, 25%) recalled locations that served turtle (noting that these were exceptions and

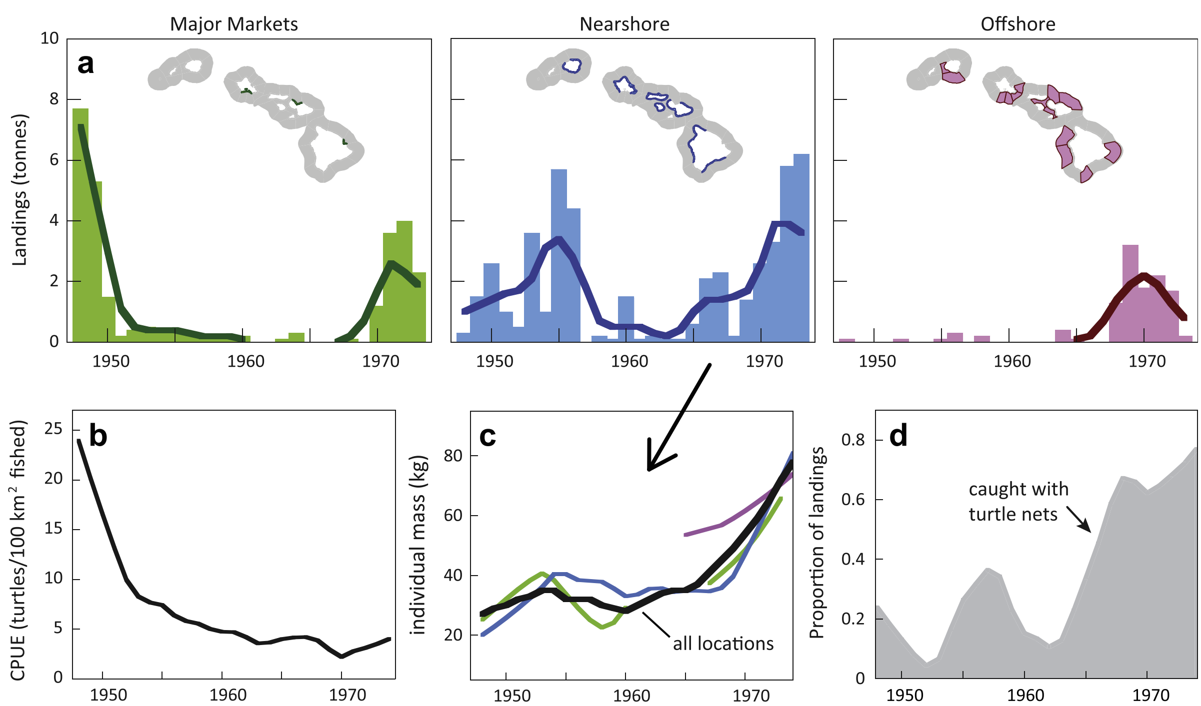

Fig. 2. CPUE declines despite the spatial expansion, progression, and gear shifts in the fishery. (a) Fishery productivity begins in the nearshore ecosystems proximate major urban sites (green – Honolulu, Kahului, and Hilo), expands to adjacent nearshore zones (blue), and then moves to previously unexploited offshore areas (pink). Inset maps locate corresponding fishery zones. Only near the fishery's end are all three regions simultaneously productive. (b) CPUE initially declines steeply, then gradually through the period. (c) The mass of harvested turtles increases over time; shifting in the late 1960s from juveniles to adults. This demographic shift corresponds to the observed spatial shifts, suggesting novel habitats were exploited. Colors correspond to locations in panel (a), black line is pooled data. (d) Landings increasingly arise from gears (turtle nets) that specifically target turtles. All lines are locally-weighted regressions.

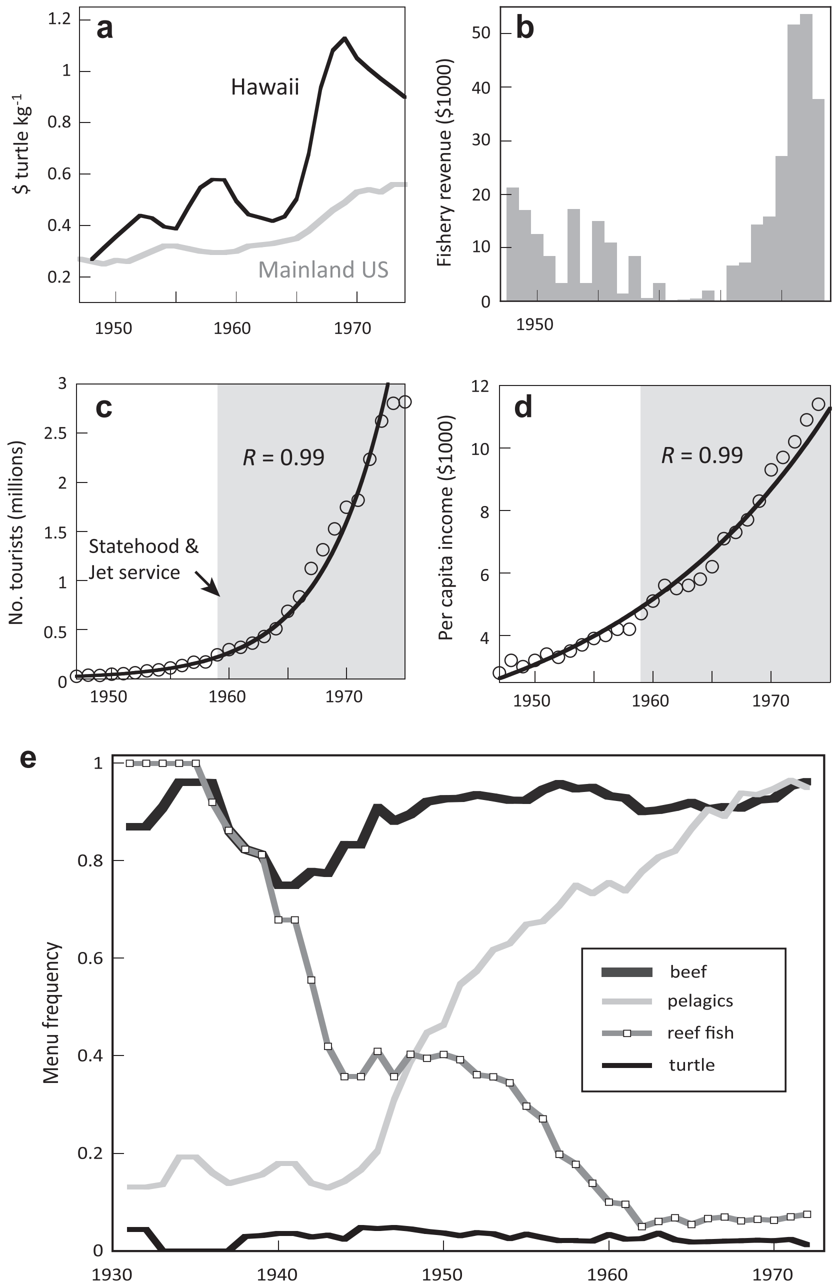

Fig. 3. Economic influences to the turtle fishery. (a) Catch value in Hawaii is consistently higher than the U.S. Mainland, and increases sharply after 1965. Black line is the smoothed Hawaii trend, grey line is a 5-year running mean for mainland U.S. values. (b) Though fishery revenues spike after 1970, inflation-adjusted revenues indicate the turtle fishery was always small in scale. (c) Hawaii tourism grew exponentially while the fishery operated, contributing to the (d) exponential growth in resident per capita income. Circles are annual statistics, lines are exponential fits, and shaded area represents statehood and commercial jet service from the U.S. Mainland. (e) Local menus indicate turtles were never commercially important for the restaurant industry. Only 10 of 371 (<3%) menus from 1912 to 1978 listed turtle. Beef was consistently common, save a brief dip during World War II (WWII). In the 1930s, nearshore fish species were on every menu, but by statehood declined to below 10%. Pelagic fish were uncommon, but increased after WWII to 90%. These trends reflect the well-known depletion of nearshore fish and the post-war expansion in offshore fishing in Hawaii.

not the norm). All five respondents who described a familiarity with fish markets, described the commercial turtle fishery as being small in scale and catering primarily to small, local fish markets who sold turtle meat directly to local residents. Three of these respondents named specific markets in Haleiwa, Oahu and in Honolulu's Chinatown where turtles were sold. Four respondents exclusively harvested turtles for non-commercial, subsistence purposes. Three respondents equated the magnitude of the commercial and subsistence turtle harvests, with one quantifying subsistence takes as roughly 50–60% of the total harvest statewide. In aggregate, these observations from key respondents involved in the fishery are consistent with our analysis of the landings data and fishery economics, describing a small-scale commercial fishery that catered primarily to local fish markets for local residents.

4. Discussion

Our analysis of commercial turtle harvests suggests that small-scale fishery exploitation and local market demand were key factors in the declines of green turtles in Hawaii. We find several significant results. First is the concave pattern in landings, with productivity peaking at the beginning and end of the fishery – landings steadily decline over the first 15 years and increase at the end (Fig. 1). Second, the fishery was a small-scale operation with limited production, revenues, and a localized market (Figs. 1 and 3). Third, even at these scales of exploitation, the fishery evidenced a serial progression, spatial expansion, and shift in gears (Fig. 2) to meet demand. Fourth, these fishery shifts are concurrent with significant declines in CPUE (Fig. 2b). Fifth, though landings initially target juveniles, they later comprise mostly adults (Fig. 2c). Taken together, our results suggest the commercial fishery contributed to deplete turtle populations locally, but that this decline occurred after centuries of prior exploitation.

The spatial dynamics of the catch and the increase in effort (Fig. 2a) show a serial progression as fishers radiated from areas adjacent to markets to unexploited nearshore zones further afield and eventually offshore. Though such patterns are canonical symptoms of local overexploitation (Pauly et al., 2002; Roberts, 2007; Rosenberg et al., 2005; Swartz et al., 2010), the concurrent declines in CPUE (Fig. 2b) and increase in market value (Fig. 3a) strongly suggest population depletion. If nearshore areas were depleted, however, what explains the renewed nearshore production in the 1970s (Fig. 2a)? When landings increased in the late 1960s, fishers switched to more extractive gears, including large turtles nets (Fig. 2d) and likely exploited different reef environments. Landing demographics exemplify this shift. For 35 years, NOAA's in-water surveys for green turtles in Hawaii predominately capture juveniles (average: 54 cm SCL, 24 kg) (Balazs and Chaloupka, 2004). These surveys use scoop-net and hand capture techniques and are restricted to the shallow back reef habitat closest to shore. From 1948 to 1965 the most common gears used to capture turtles were hand lines and various other shore-based gears. These gears would have operated in the same back reef environs of NOAA's recent surveys, and it is unsurprising that they interacted with the same demographic (Fig. 2c). Demographic shifts in the latter years of the fishery likely arose from a new focus on the fore reef and offshore zones and from the increasing use of turtle nets. Historical accounts (Beckley, 1883; Bingham and Stokes, 1906; Fornander and Thrum, 1919) of these gears describe them as immense bag nets measuring up to 70 m by 35 m. These gears likely captured population segments that the hand lines and other gears previously missed. Despite the refocus on nearshore environs in the late 1960s and the use of more extractive gears, CPUE remains depressed (Fig. 2b), however.

Understanding the precise mechanisms for historical population decline is important for contemporary management. Previous studies suggested that the root cause of the near-extinction of Hawaiian green turtles was tourism-based demand, through restaurants (Balazs, 1980; Chaloupka and Balazs, 2007). The spike in landings after 1960 (Fig. 1a) is indeed consistent with the advent of tourism (Fig. 3c). Our analysis indicates, rather, this relationship is not directly causal, but likely from increasing local income (Fig. 3d). Two key pieces of evidence support this claim. First, turtle was largely absent (Fig. 3e) on the extensive collection of restaurant menus we surveyed (Van Houtan et al., 2013). Second, our interviews document that turtle was primarily sold as processed meat to local residents at neighborhood fish markets. Together this indicates that market demand for the fishery was driven by local demand. The increases after 1960 may therefore bear only an indirect relationship to tourism, through rising local resident income (Fig. 3d) and purchasing power.

Though local, small-scale fisheries can have dramatic population-level impacts (Hawkins and Roberts, 2004; Jennings and Polunin, 1996; Newton et al., 2007; Polunin and Sumertha Nuitja, 1995), how such a limited harvest pressure affected this turtle population deserves explanation. We analyzed official fishery records, which are not a full account of turtle harvests in Hawaii during this period. Many of the respondents we interviewed harvested turtles both for subsistence use and for commercial profit. Their collective estimate was that the commercial fishery was roughly half of the total green turtle harvest in Hawaii during this period – undocumented subsistence takes composed the rest. Based on our landings analysis and respondent estimates, the cumulative harvest from recreational and commercial takes was 5000–6000 turtles over 26 years – roughly 180–230 turtles a year. Such annual totals during this period reportedly occurred historically in Hawaii during a single day (Amerson et al., 1974; Clapp and Wirtz, 1975; Kittinger et al., 2011; Van Houtan et al., 2012). Thus, the population of Hawaiian green turtles was likely already significantly depleted by 1945 (Kittinger et al., 2013; Van Houtan et al., 2012) allowing such limited harvests to achieve significant population impacts. The uncertainty in historical harvests, however, also highlights the limitations of historical records, even when they consist of detailed fishery reports and economic data series. Future efforts to understand aggregate fishing power (Smith, 2004), account for zero catch trips, or to calculate underreporting of landings (Zeller et al., 2008) may help resolve such uncertainties.

Historical ecology will be increasingly appreciated outside of academic circles if managers understand its practical application. We provide several examples. First, recent scientific surveys are an incomplete resource for long-term conservation planning. Centuries of indigenous and colonial-era exploitation extirpated major green turtle nesting areas in Hawaii, leaving only one major rookery by the mid-1900s (Kittinger et al., 2013). Our CPUE series (Fig. 2b) chronicles an even further decline from 1948 to 1974. Thus, when scientific monitoring began at the principal nesting rookery in 1973, the population was likely at an unprecedented historical bottleneck. Given this, "objective, measurable criteria" to define recovery as stipulated in the U.S. Endangered Species Act (ESA) Section 4 (f)(1)(B)(ii) should probably pre-date surveys that begin at this low point. In this vein, a recent analysis documented that 80% of the historically major nesting populations have been essentially extirpated, suggesting that today's breeding population is unnaturally concentrated in one single location (Kittinger et al., 2013). (By contrast, however, The IUCN recently revised the population to "Least Concern" status (Pilcher et al., 2012) without considering the population's history of exploitation or the historical loss of major nesting areas.) Second, though historical information is beneficial for single-species assessments, it might be a greater priority for ecosystem-based management. Coral reefs in the Main Hawaiian Islands, for example, have declined significantly in the past few centuries (Kittinger et al., 2011). For sea turtles, nearshore eutrophication and introduced species have displaced their native food sources (Smith et al., 2002) and are implicated in a debilitating tumor-forming disease (Van Houtan et al., 2010). As a result, knowing whether the current ecosystem could support the population abundance of centuries past remains a complex challenge. Third, socioeconomic factors can help interpret historical population declines and manage today's threats. In our study, socioeconomic data helped document the limited scale of the fishery (Fig. 3) and its market drivers (Van Houtan et al., 2013). Similar findings elsewhere describe how localized, small-scale exploitation can deplete protected populations (Eddy et al., 2010; Kirby, 2004). This information can be used in ESA and IUCN status reviews, as well as biological assessments of proposed federal actions, to generally understand long-term population health.

As previously exploited populations recover across the globe, detailing how ecosystems arrived to their current state is critical. Here we describe how a chronically exploited population was driven even closer to extinction by a small-scale commercial harvest. The modern scientific monitoring that began late in this history, is an incomplete account of the population and is itself insufficient for gauging long-term recovery. Though this presents new and sometimes complex scientific and management challenges, incorporating historical data streams provides critical new information that will help in developing recovery targets at ecologically and historically relevant timescales.

Author contributions

KV designed the study, performed the analyses, and prepared the figures. KV and JK contributed data and wrote the manuscript. All authors reviewed the manuscript.

Acknowledgments

This is the third paper from the NOAA Pacific Sea Turtle Historical Ecology Working Group. D. Hamm, K. Lowe, R. Kokobun, and K. Kawamoto provided logbook data. B. Takenaka, P. Nogelmeier, A. Katekaru, A. Chau, and A. Hiura provided cultural information on turtle fishing in Hawaii. G. Engebreston, M. Payne, T. Kiliki, D. Evans, R. Umehira, D. Brown and the Bishop Museum archives staff assisted with restaurant menus. M. Brooker, K. Takahashi, and A. Au assisted with economic data. V. Saba, F. Parrish, L. Van Atta, T. Jones, L. McClenachan, and three anonymous reviewers made improvements to an earlier version of this manuscript. We thank interviewees for sharing their expert knowledge about the Hawaiian green sea turtle fishery. The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and do not necessarily reflect those of NOAA or the Department of Commerce.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2013.11.011.

References

Allen, R., 2004. Creating Hawaii tourism. Bess Press, Honolulu.
Allen, M.S., 2007. Three millennia of human and sea turtle interactions in remote Oceania. Coral Reefs 26, 959–970.
Amerson, A.B., 1971. The natural history of the French Frigate Shoals, Northwestern Hawaiian Islands. Atoll. Res. Bull. 150, i-383.
Amerson Jr., A.B., Clapp, R.B., Wirtz, W.O., 1974. The natural history of Pearl and Hermes Reef, Northwestern Hawaiian Islands. Atoll. Res. Bull. 174, 1–306.
Balazs, G.H., 1980. Synopsis of Biological Data on the Green Turtle in the Hawaiian Islands. NOAA Technical Memorandum, NOAA Fisheries, Honolulu, HI.
Balazs, G.H., Chaloupka, M., 2004. Spatial and temporal variability in the somatic growth of green sea turtles (Chelonia mydas) resident in the Hawaiian Archipelago. Mar. Biol. 145, 1043–1059.
Beckley, E.M., 1883. Hawaiian Fisheries and Methods of Fishing with an Account of the Fishing Implements used by the Natives of the Hawaiian Islands. Hawaii Ministry of Foreign Affairs, Honolulu.
Bernard, H.R., 2011. Research Methods in Anthropology: Qualitative and Quantitative Approaches. Altamira Press, Oxford, UK.
Bickman, L., Rog, D.J., 2009. The Sage Handbook of Applied Social Research Methods. SAGE Publications, Incorporated.
Bingham, W.T., Stokes, J.F.G., 1906. Hawaiian mat and basket weaving and nets and netting. Memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology and Natural History 2, 1–163.
Bjorndal, K.A., Jackson, J.B.C., 2003. Roles of sea turtles in marine ecosystems: reconstructing the past. In: Lutz, P.L., Musick, J.A., Wyneken, J. (Eds.), The Biology of Sea Turtles, vol. II. CRC Press, Boca Raton, FL, pp. 259–273.
Bjorndal, K.A., Bowen, B.W., Chaloupka, M., Crowder, L.B., Heppell, S.S., Jones, C.M., Lutcavage, M.E., Solow, A.R., Witherington, B.E., 2010. Assessment of Sea-turtle Status and Trends: Intergrating Demography and Abundance. National Academies Press, Washington DC.
Boland, R.C., Parrish, F.A., 2005. A description of fish assemblages in the black coral beds off Lahaina, Maui. Hawaii. Pac. Sci. 59, 411–420.
Bryan, W.A., 1915. Natural History of Hawaii. The Hawaiian Gazette Company, Honolulu, HI.
Chaloupka, M., Balazs, G., 2007. Using Bayesian state-space modelling to assess the recovery and harvest potential of the Hawaiian green sea turtle stock. Ecol. Model. 205, 93–109.
Clapp, R.B., Wirtz, W.O., 1975. The natural history of Lisianski Island, Northwestern Hawaiian Islands. Atoll. Res. Bull. 186, 1–196.
Cleveland, W.S., Devlin, S.J., 1988. Locally weighted regression: an approach to regression analysis by local fitting. J. Am. Stat. Assoc. 83, 596–610.
Cobb, J.N., 1905. Section III. The commercial fisheries. In: Jordan, D.S., Evermann, B.W. (Eds.), The Aquatic Resources of the Hawaiian Islands. Goverment Printing Office, Washington DC, pp. 715–765.
Conant, T.A., Dutton, P.H., Eguchi, T., Epperly, S.P., Fahy, C.C., Godfrey, M.H., MacPherson, S.L., Possardt, E.E., Schroeder, B.A., Seminoff, J.A., Snover, M.L., Upite, C.M., Witherington, B.E., 2009. Loggerhead sea turtle (Caretta caretta) 2009 status review under the U.S. Endangered Species Act. National Marine Fisheries Service, Silver Spring, MD.
Eddy, T.D., Gardner, J.P.A., Pérez-Matus, A., 2010. Applying fishers' ecological knowledge to construct past and future lobster stocks in the Juan Fernández Archipelago, Chile. PLoS ONE 5, e13670.
Elschner, C., 1915. The Leeward Islands of the Hawaiian Group. Sunday Advertiser, Honolulu.
ESRI, 2009. ArcMap. Environmental Systems Research Institute Inc., Redlands, CA.
Fornander, A., Thrum, T.G., 1919. Fornander collection of Hawaiian antiquities and folklore. Memoirs of the Bernice Pauahi Bishop Museum of Polynesian Ethnology and Natural History 6, 1–556.
Friedlander, A., Aeby, G., Brainard, R., Brown, E., Chaston, K., Clark, A., McGowan, P., Montgomery, T., Walsh, W., Williams, I., Wiltse, W., 2008. The state of coral reef ecosystems of the Main Hawaiian Islands. In: Waddell, J.E., Clarke, A.M. (Eds.), The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States. Silver Spring, MD, NOAA/NCCOS Center for Coastal Monitoring, pp. 219–253.
Hawkins, J.P., Roberts, C.M., 2004. Effects of artisanal fishing on Caribbean coral reefs. Conserv. Biol. 18, 215–226.
Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., Warner, R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293, 629–637.
Jennings, S., Polunin, N., 1996. Effects of fishing effort and catch rate upon the structure and biomass of Fijian reef fish communities. J. Appl. Ecol., 400–412.
Kirby, M.X., 2004. Fishing down the coast: historical expansion and collapse of oyster fisheries along continental margins. Proc. Natl. Acad. Sci. USA 101, 13096–13099.
Kittinger, J.N., Pandolfi, J.M., Blodgett, J.H., Hunt, T.L., Jiang, H., Maly, K., McClenachan, L.E., Schultz, J.K., Wilcox, B.A., 2011. Historical reconstruction reveals recovery in Hawaiian Coral Reefs. PLoS ONE 6, e25460.
Kittinger, J.N., Van Houtan, K.S., McClenachan, L., Lawrence, A.L., 2013. Using historical data to assess the biogeography of population recovery. Ecography 36, 868–872.
Kvale, S., 1996. Interviews: An Introduction to Qualitative Research Interviewing. Sage Publications, Thousand Oaks, CA.
Lotze, H., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M., Kirby, M.X., Peterson, C.H., Jackson, J.B.C., 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312, 1806–1809.
Lotze, H.K., Coll, M., Magera, A.M., Ward-Paige, C., Airoldi, L., 2011. Recovery of marine animal populations and ecosystems. Trends. Ecol. Evol. 26, 595–605.
McClenachan, L., Jackson, J.B.C., Newman, M.J.H., 2006. Conservation implications of historic sea turtle nesting beach loss. Front. Ecol. Environ. 4, 290–296.
McClenachan, L., Ferretti, F., Baum, J.K., 2012. From archives to conservation: why historical data are needed to set baselines for marine animals and ecosystems. Conserv. Lett..
Myers, R.A., Worm, B., 2003. Rapid worldwide depletion of predatory fish communities. Nature 423, 280–283.
Newton, K., Cote, I.M., Pilling, G.M., Jennings, S., Dulvy, N.K., 2007. Current and future sustainability of island coral reef fisheries. Curr. Biol. 17, 655–658.
Nmfs, U., 2007a. (2007) Green Sea Turtle (Chelonia mydas) 5-year Review: summary and Evaluation. NOAA Fisheries, Silver Spring, MD.
Nmfs, U., 2007b. (2007) Hawksbill Sea Turtle (Eretmochelys imbricata) 5-year Review: Summary and Evaluation. NOAA Fisheries, Silver Spring, MD.
NOAA, 2012. Endangered and threatened wildlife; 90-Day finding on a petition to delist the green turtle in Hawaii and notice of status review. Federal Register 77, 45571–45574.
O'Donnell, K.P., Molloy, P.P., Vincent, A.C., 2012. Comparing fisher interviews, logbooks, and catch landings estimates of extraction rates in a small-scale fishery. Coast. Manage. 40, 594–611.
Pandolfi, J.M., Bradbury, R.H., Sala, E., Hughes, T.P., Bjorndal, K.A., Cooke, R.G., McArdle, D., McClenachan, L., Newman, M.J.H., Paredes, G., Warner, R.R., Jackson, J.B.C., 2003. Global trajectories of the long-term decline of coral reef ecosystems. Science 301, 955–958.
Pauly, D., 1995. Anecdotes and the shifting baseline syndrome of fisheries. Trends. Ecol. Evol. 10, 430.
Pauly, D., Christensen, V., Guenette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., Zeller, D., 2002. Towards sustainability in world fisheries. Nature 418, 689–695.
Pilcher, N.J., Chaloupka, M.Y., Woods, E., 2012. Chelonia mydas Hawaiian subpopulation. IUCN Red List of Threatened Species 2012, 1.
Polunin, N.V.C., Sumertha Nuitja, N., 1995. Sea turtle populations of Indonesia and Thailand. In: Bjorndal, K.A. (Ed.), Biology and Conservation of Sea Turtles. Smithonsinan Institution Press, Washington, DC, pp. 353–362.

Rick, T.C., Erlandson, J.M., 2009. Coastal exploitation. Science 325, 952–953.
Roberts, C., 2007. The Unnatural History of the Sea. Island Press.
Rosenberg, A.A., Bolster, W.J., Alexander, K.E., Leavenworth, W.B., Cooper, A.B., McKenzie, M.G., 2005. The history of ocean resources: modeling cod biomass using historical records. Front. Ecol. Environ. 3, 78–84.
Schmitt, R.C., 1977. Historical Statistics of Hawaii. University Press of Hawaii, Honolulu.
Smith, M.D., 2004. Limited-entry licensing: insights from a duration model. Am. J. Agric. Econ. 86, 605–618.
Smith, J.E., Hunter, C.L., Smith, C.M., 2002. Distribution and reproductive characteristics of nonindigenous and invasive marine algae in the Hawaiian Islands. Pac. Sci. 56, 299–315.
Snover, M.L., 2008. Comments on "using Bayesian state-space modelling to assess the recovery and harvest potential of the Hawaiian green sea turtle stock". Ecol. Model. 212, 545–549.
Swartz, W., Sala, E., Tracey, S., Watson, R., Pauly, D., 2010. The spatial expansion and ecological footprint of fisheries (1950 to present). PLoS ONE 5, e15143.
Titcomb, M., 1972. Native Use of Fish in Hawaii. University of Hawaii Press, Honolulu.
Van Houtan, K.S., Pimm, S.L., Halley, J.M., Bierregaard, R.O., Lovejoy, T.E., 2007. Dispersal of Amazonian birds in continuous and fragmented forest. Ecol. Lett. 10, 219–229.
Van Houtan, K.S., Hargrove, S.K., Balazs, G.H., 2010. Land use, macroalgae, and a tumor-forming disease in marine turtles. PLoS ONE 5, e12900.
Van Houtan, K.S., Kittinger, J.N., Lawrence, A.L., Yoshinaga, C., Born, R., Fox, A., 2012. Hawksbill sea turtles in the Northwestern Hawaiian Islands. Chel. Conserv. Biol. 11, 117–121.
Van Houtan, K.S., McClenachan, L., Kittinger, J.N., 2013. Seafood menus reflect long-term ocean changes. Front. Ecol. Environ. 11, 289–290.
Witzell, W., 1994. The origin, evolution, and demise of the U.S. sea turtle fisheries. Mar. Fish. Rev. 56, 8–23.
Zeller, D., Darcy, M., Booth, S., Lowe, M., Martell, S., 2008. What about recreational catch?: potential impact on stock assessment for Hawaii's bottomfish fisheries. Fish. Res. 91, 88–97.
Zu Ermgassen, P.S., Spalding, M.D., Blake, B., Coen, L.D., Dumbauld, B., Geiger, S., Grabowski, J.H., Grizzle, R., Luckenbach, M., McGraw, K., 2012. Historical ecology with real numbers: past and present extent and biomass of an imperilled estuarine habitat. Proc. R. Soc. B. 279, 3393–3400.