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Historical commercial exploitation and the current status of Hawaiian green turtles

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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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(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.