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RESEARCH ARTICLE

Hedonic price model of Hawai'i 'Ahi Tuna (*Thunnus obesus* and *Thunnus albacares*) market: Implications of climate change and shark depredation

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Abstract

In Hawai'i, the prices of 'ahi tuna, i.e., bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*), are influenced by numerous factors. This study utilizes a hedonic price model to estimate tuna price using fish characteristics, trip-specific information, daily market conditions, foreign imports, individual seller effects, and time effects. Sea surface temperature (SST) at the fishing location and trip length are used as proxies for fish quality. Higher SST and longer trip length are associated with lower fish prices, reflecting their negative impact on quality. The study provides important implications of climate change on future tuna prices in Hawai'i. In addition to higher SST, climate change impacts on tuna habitat, leading to increased vessel travel distances; climate-induced reductions in tuna body size; and climate effects on tuna abundance, biomass, spatial distribution, and catchability, which affect daily supply—all have significant effects on tuna prices. The study also estimates the price impact of shark depredation and assesses its negative effect on revenue.

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Introduction

Description of Hawai'i tuna fishery and fish auction

The Hawai'i longline fishery is the primary commercial fishery in the state. The fishery uses deep-set longlines, which stretch between 30 and 60 miles, carry approximately 3,000 baited hooks per line, and are set during daytime at depth around 300 meter to target bigeye tuna (*Thunnus obesus*). It also uses shallow-set longlines, which stretch between 20 and 40 miles, carry about 1,200 baited hooks per line, and are set during nighttime at depths around 50 meters to target swordfish (a'u kū; *Xiphias gladius*). Approximately 80% of landings from the deep-set longline fishery are sold locally as fresh, ice-chilled products, primarily 'ahi tuna, i.e., bigeye tuna and yellowfin tuna (*Thunnus albacares*). Other landings include albacore tuna ('ahi palaha; *Thunnus alalunga*), skipjack tuna (aku; *Katsuwonus pelamis*), and other pelagic species such as mahimahi (*Coryphaena hippurus*), sickle pomfret (mukau; *Taractichthys steindachneri*), wahoo (ono; *Acanthocybium solandri*), striped marlin (a'u kī; *Kajikia audax*),

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blue marlin (aʻu; *Makaira nigricans*), shortbill spearfish (aʻu kī; *Tetrapturus angustirostris*), and opah (*Lampris incognitus & L. magalopsis*). In contrast, a significant portion of swordfish caught by the shallow-set longline fishery is frozen and shipped to the U.S. mainland. The higher value of bigeye tuna relative to swordfish in recent years has led to the deep-set longline fishery becoming the main fishery in Hawaiʻi. In 2023, the Hawaiʻi longline fishery operated 147 active vessels with an average length of 73 feet, completing 1,569 deep-set trips and 71 shallow-set trips. Driven by the sale of fresh tuna, the value and the volume of seafood landed in Honolulu ranked the 6th ($112.9 million) and 25th (26.7 million lb) in the U.S. ports in 2023, respectively [1].

Most of the fish from the Hawaiʻi longline fishery are landed at the Honolulu port and sold at the Honolulu fish auction. The auction provides a centralized marketplace for sellers and buyers, playing a significant role in facilitating the determination of market prices. The Honolulu fish auction was established as a similar model to the Tokyo fish auction. It auctions fresh fish, mostly bigeye and yellowfin tuna, as well as other pelagic fish, Monday to Saturday. It also opens on Sunday during the last two weeks of December when demand for fresh tuna is high for holiday celebrations. Fishers can sell at the Honolulu fish auction once they register and get a permit from the United Fishing Agency (UFA), the company that has owned and operated the Honolulu fish auction since it was established in 1952. The UFA keeps detailed records of fish sold at the auction including transaction date, species, sold value, fish price, weight, fish condition, and the longline trip that caught the fish. As most of the bigeye and yellowfin are sold individually, the data record for each individual fish is quite detailed. For larger tuna, a small piece of flesh is cored and/or cut off near the tail area so that buyers can examine the quality of flesh. Buyers can examine an individual fish for quality before bidding on it, so the price reflects willingness to pay for the specific quality of the fish. Freshness is an important component for the quality of bigeye and yellowfin tuna as oftentimes they are eaten raw.

The Honolulu fish auction represents the largest food producing industry in Hawaiʻi. The amount of fish going through the auction per month could feed approximately one lb of fish to the entire population of the state plus the total visitors to Hawaiʻi in a month. The auction's role in providing local food security is particularly important given Hawaiʻi's isolated location and local culture of high seafood consumption [2]. Since the Hawaiʻi longline fishery is the major fishery supporting the Honolulu fish auction, and the sustainability of its operation depends largely on the value of fish it produces, it is important to understand how different factors contribute to fish price variation.

Tuna quality and price

The operation of the Hawaiʻi longline fishery is influenced by numerous factors such as climate change [3,4], environmental factors [5,6], shark depredation [7,8], and market conditions [9–11]. These components influence fish quality, fish size, total daily landings, and the resulting value of fish.

High sea surface temperature (SST) can burn the muscle of the fish [11] and reduce its fatty acid content [12], thereby degrading the fish's quality. Therefore, fish that are caught in lower SST should be better quality. Pan and Pooley [13] found that SST did affect the price of bigeye tuna in the Hawaiʻi longline fishery. They used weekly average SST within the common fishing ground of Hawaiʻi longline fishery (300 nautical miles around the main Hawaiian Islands) as the quality measure to estimate the price of bigeye tuna in Hawaiʻi. They observed that the Hawaiʻi longline fishery landed lower quality bigeye during the summer and higher quality during the winter (in years 1994–1996) which was attributed to the temperature differences. Their fish price model found that a 1 °F increase in SST was associated with $0.21 reduction in the price of bigeye tuna. However, the recent fishing pattern of the Hawai'i longline fleet has shifted with the expansion of fishing ground further to the northeast of the main Hawaiian Islands in the third quarter [6] where fishing grounds are cooler. Fig 1 shows the monthly average SST for fishing haul location for the deep-set longline fishery between 1994 and 2023. One obvious change is the drop in SST during the third quarter over the past 20 years compared to the earlier period from 1994 to 2003. The changing spatial distribution of fishing operations and the SST at hauling location could potentially affect the quality of fish landed by the fishery.

Comparing the monthly SST (Fig 1) with the monthly fish price (Fig 2) reveals the potential impact of SST on fish quality. The average monthly bigeye and yellowfin prices at UFA demonstrates some annual and monthly patterns. Note that 2021 was an exceptional year for fish prices, as visitor arrivals to Hawai'i began to accelerate in March 2021 following the pandemic. In contrast, for the more normal years of 2022 and 2023, fish prices were lowest between September and November, which aligns with the high SST observed at the fishing locations (Fig 1).

A typical deep-set longline fishery trip lasts several weeks to more than a month; fish are not frozen but chilled to preserve freshness. Fish caught on a shorter trip are expected to be fresher than those caught on a longer trip. The trip travel distance of the Hawai'i deep-set longline fishery has found to be affected by climate change [3]. The higher SST overall in the North Pacific Ocean has driven the fleet to travel further into cooler waters. Climate change has changed the spatial distribution of target species and fishing operations which, in turn, could impact fish freshness and fish prices.

Another variable that may affect tuna quality and price is shark depredation. The incidence of damage caused by cookie cutter sharks (*Isistius brasiliensis*), other sharks, and other factors to the species landed by the Hawai'i longline fishery is a persistent phenomenon (Fig 3 and Fig 4). From the 2021 to 2023 UFA data, 14.3% of sales were damaged by cookie cutter sharks with 1 to 3 bites, 0.2% were damaged by cookie cutter sharks with 4 or more bites, 0.5% were damaged by other sharks, and 0.8% had other damage (not from sharks). The incidences

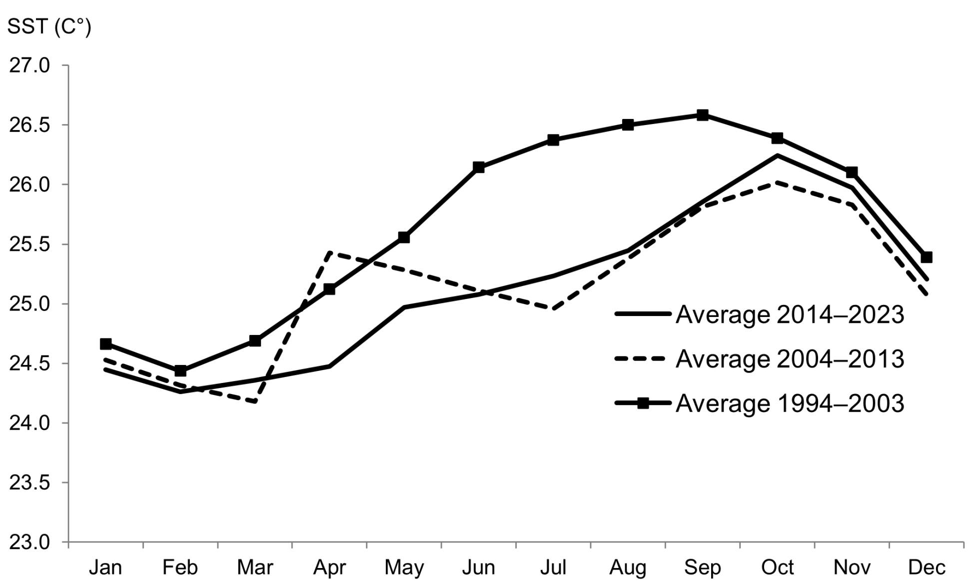

Fig 1. Average monthly SST for fishing haul location, 1994–2003, 2004–2013, 2014–2023.

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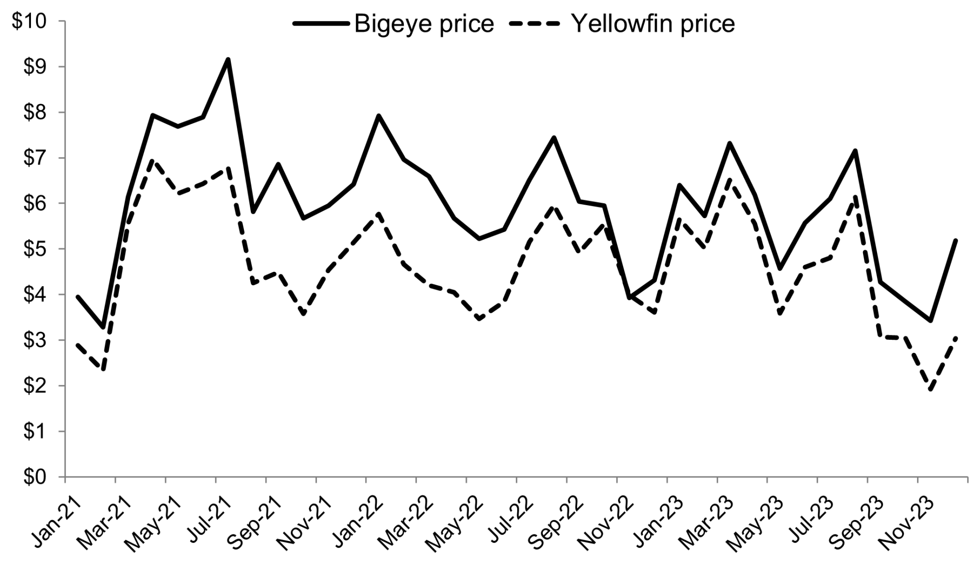

Fig 2. Average monthly bigeye and yellowfin price per lb, inflation adjusted to 2023 dollar.

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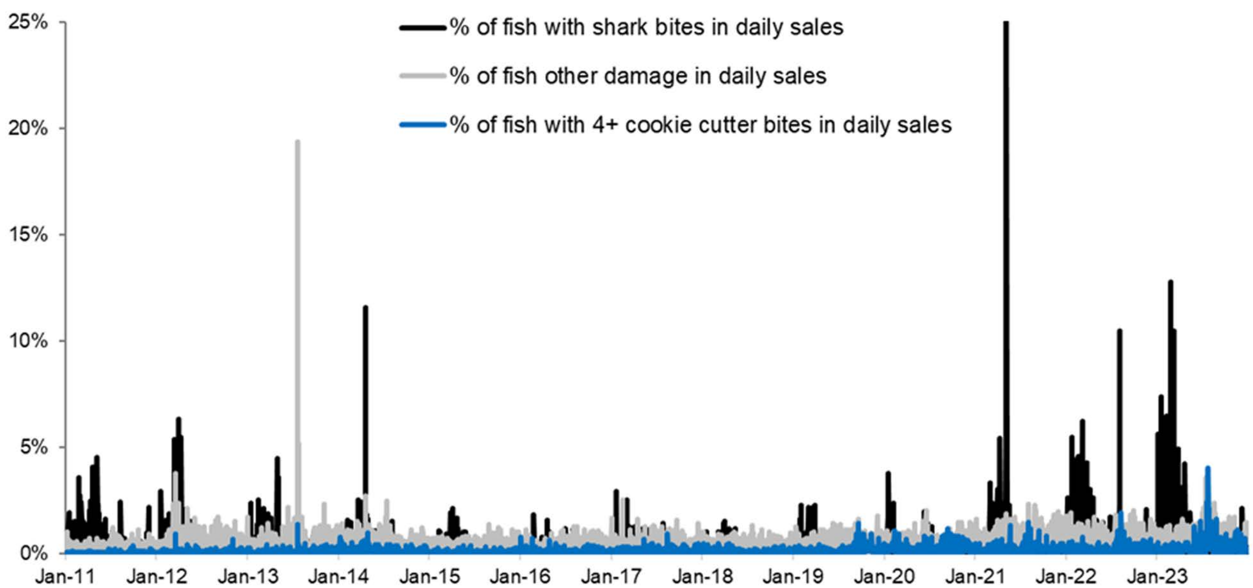

Fig 3. Percent of fish with shark depredation and other damage in daily landings, 2011 to 2023.

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of cookie cutter bites and shark damages show increasing trends; the highest incidences happened in 2023. Fig 3 shows the incidence of fish with more serious cookie cutter bites (4 or more), other shark depredation, and other damage. There are relatively fewer of these incidences compared with those with minor cookie cutter bites (1 to 3) in Fig 4, but there also seems to have been an increasing trend in 2021–2023. Please note that the UFA data include only fish that made it to the auction floor. There are other instances of depredation where the entire fish is lost on the line or simply too damaged to make it to auction.

The vertical migration patterns of cookie cutter sharks coincide with the Hawai'i deep-set longline fishery operations on a daily scale. Cookie cutter sharks migrate vertically, remaining

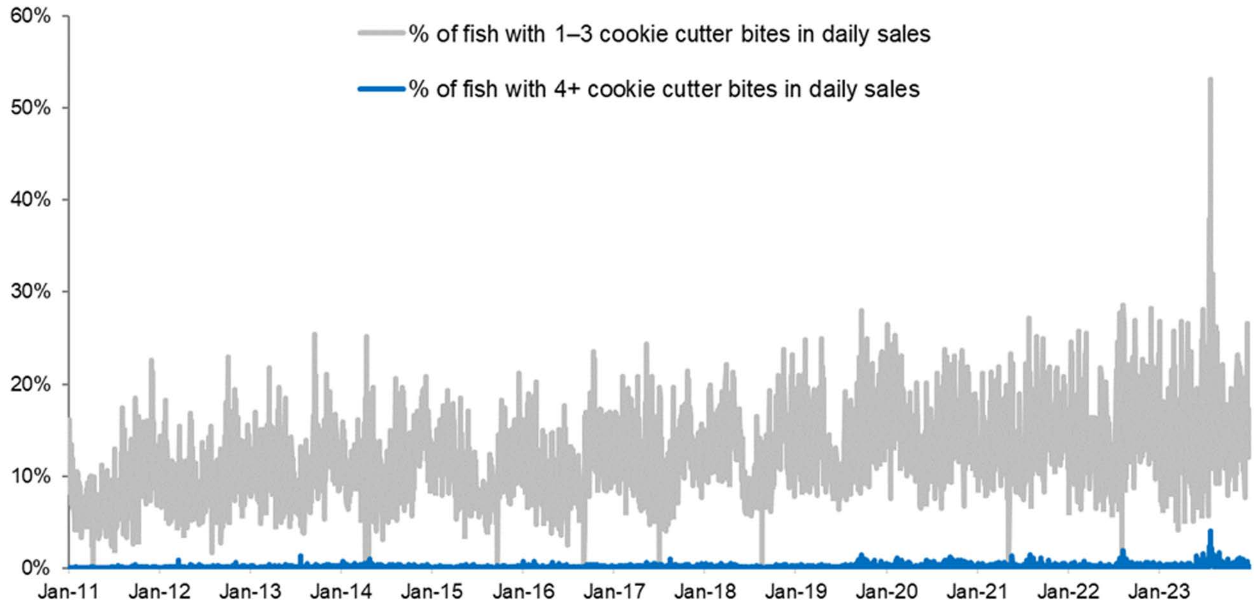

Fig 4. Percent of fish with cookie cutter bites in daily landings, 2011 to 2023.

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deep during the day and rising nearer the surface at night; the deep-set longline fishery sets the hooks early in the morning, begins to haul in the late afternoon, and continues until late at night [14]. However, little is known about their exact depths during day and night beyond general understanding of vertically migrating behavior by adults through dietary tracers [15]. Cookie cutter sharks prey on larger pelagic fishes, elasmobranchs, and cetaceans with small, generally non-fatal bite wounds. Such bite wounds are also found on fish landed by the Hawai'i longline fishery, which can be a combination of natural attacks in the wild and attacks exacerbated by fish catch dangling on the longline gear. Fresh bites are likely primarily the latter. A study by Papastamatiou et al. [16] found that swordfish, opah, bigeye tuna, and yellowfin tuna were the four species with the highest incidences of cookie cutter shark bites in the Hawai'i longline fishery. The estimated length of cookie cutter sharks which interacted with the Hawai'i longline fishery was between 13 cm and 53 cm, and the bite size ranged from 1 cm to 10 cm [16]. Depending on the position of the damage (e.g., whether it is in the filet area) and the number of bites, the value of fish bitten by cookie cutter sharks is likely to vary. Besides cookie cutter sharks, depredation of catch by other sharks (such as shortfin mako *Isurus oxyrinchus*) is commonplace in the longline fishery, is much more damaging to individual fish, and causes economic losses [8].

Another important quality affecting fish price is weight, as larger tuna typically translates into higher fish price per lb [11]. Additionally, fish species can influence fish price, as McConnell & Strand [11] pointed out that in the Hawai'i fish auction market, bigeye tuna consistently commanded higher prices than yellowfin and albacore tunas.

Daily market conditions and price

Market conditions play a crucial role in determining fish prices, as the auction operates daily until the supply is exhausted. Given that most of the bigeye and yellowfin are consumed locally rather than exported, fish prices are more likely to be influenced by local market conditions than by global market trends. Therefore, fluctuations in daily market conditions, such as the total quantity of fish supplied in a day and the demand from local residents and visitors, can influence fish prices. Market demand fluctuations due to events like the pandemic and the Maui fire in 2023 which impact visitor arrivals can affect daily fish prices. Daily visitor count in Hawaiʻi before and after the pandemic was around 20,000 to 40,000, and their demand for local fresh fish is high. The impact of visitor demand on fish prices was especially apparent in the beginning of the pandemic; prices at the Honolulu fish auction dropped significantly on March 14, 2020, around the time when visitor arrivals started to plummet. Average daily bigeye price (inflation adjusted) was over $3/lb before March 14, 2020, and it dropped to $2.05/lb on March 14, 2020, $1.05/lb on March 16, 2020, and $0.9/lb on March 17, 2020. Holiday season, especially towards the end of the year, produces a price premium as the local demand for sashimi peaks for New Year celebrations. Local fresh tuna is often used to make poke, a traditional Hawaiian dish that is a local favorite and popular with visitors. While fresh poke can be costly, a more affordable version is available using previously frozen tuna, primarily imported from Southeast Asian countries. The fishing industry in Hawaiʻi is concerned about the competition from these foreign tuna imports, as they act as substitutes for local tuna and can affect local prices. Between 2021 and 2023, monthly frozen tuna imports to Hawaiʻi averaged nearly half a million lb. In contrast, imports of fresh bigeye and yellowfin tuna were considerably lower, measured in thousands of lb; nearly half of the months showed no imports.

The objective of this study is to develop a hedonic fish price model for bigeye and yellowfin tuna sold at the Honolulu fish auction between 2021 and 2023, and to examine and quantify how various factors contribute to the daily variation in fish prices. This research is made possible by the availability of a uniquely detailed fish auction dataset, which records individual tuna characteristics including weight, price, condition, the vessel, and the specific fishing trip in which the fish was caught. Additionally, this dataset can be linked with a logbook to identify trip-specific details, including duration, as well as the location and environmental conditions of the fishing hauls. The study provides an updated Hawaiʻi fish price model that incorporates some of the commonly used determinants in the hedonic price model for seafood markets, such as daily fish supply, fish size, seller characteristics, time/seasonal effects, and trip length. Furthermore, it introduces new determinants to explore their impacts on price, including climate factors such as SST at the time of haul, specific fish condition such as shark depredation and other damages, and market conditions like visitor arrivals and foreign imports. Using statistical methods to analyze the determinants of daily fish prices in Honolulu, some important issues can be explored. One is the impact of higher SST on tuna prices, linking it to the degradation of fish quality. Another topic is that increased trip lengths—potentially driven by climate change impacts on tuna habitat [3]—negatively affect tuna prices due to longer storage times, which can compromise freshness. Additionally, reductions in tuna body size, another possibly outcome of climate change [17], could lead to lower prices, as larger tuna command price premiums [11]. Daily fish supply could be influenced by climate change through its effects on tuna abundance [18,19], biomass [4,20], catchability [21,22], and spatial distribution [23,24], which in turn play a role in determining fish prices and revenue. Furthermore, the fishing industry has been concerned about the rising occurrences of cookie cutter sharks and other shark depredation in Hawaiʻi longline catches and the associated economic loss. This study provides estimations of price impacts and revenue loss due to such depredation. To date, limited literature has incorporated environmental variables into hedonic fish price modeling to explore the potential impacts of climate change on fish prices. Understanding these climate change implications for tuna prices provides valuable insights for the fishing industry, helping stakeholders to adapt their operations to changing environmental conditions and sustain economic viability.

Materials and methods

Model

This study uses a hedonic price model to estimate the value of distinct attributes of tuna on auction price. Hedonic price models are frequently used in the field of economics to quantify the economic value of distinct attributes of goods and services. Hedonic techniques have been applied to commodities such as hotels and real estate [25–28], environmental resources [29–31], and seafood [11,32–37]. In Hawai'i, McConnell & Strand [11] used 1994 and 1995 Hawai'i fish auction data to examine the Hawai'i tuna price using variables such as fish size, fat content, quality of fish, daily landings, and gear type. Pan & Pooley [13] also examined the Hawai'i tuna price between 1994 and 1996 using a price-dependent equation that included lagged fish price, landings of major species, weekly average SST of Hawai'i longline fishing grounds, and holiday variables. However, these studies, conducted nearly 30 years ago, do not reflect the significant changes in the spatial distribution of Hawai'i longline fishing efforts or the evolving environmental and market conditions.

In this study, the hedonic price model used to estimate tuna price per lb includes variables that reflect the fish characteristics, trip-specific information, daily market conditions, individual seller effects, and time effects. Fish characteristics utilize proxy variables for quality as this attribute is not directly recorded in the auction. These proxies include SST at the fishing location and duration between trip departure date and fish sale date.

Freshness is an important quality that affects the price of fresh fish. However, there is no standardized measurement for fish freshness. In the literature, hedonic models for fish price used time-based variables such as trip duration and storage time as a proxy for fish freshness [35]. Although we are not able to identify the specific date that the fish was caught, shorter trips should yield fresher fish than longer trips. Therefore, we use the duration between the trip departure date and fish sale date as a proxy for freshness. SST is another factor that could affect tuna quality and prices [13]. McConnell & Strand [11] used the degree of burn on fish muscle as a measurement of quality and identified warm water during summer as the likely factor causing burned fish which affected fish price negatively. A trip that travels to higher latitudes is expected to encounter lower SST compared to one that remains closer to the Honolulu port on the same day, linking fish quality to the spatial distribution of the fishing trip. The estimation of tuna price also accounts for potential damage to the fish, which is expected to lower the price. Variables which indicate if the fish was damaged by cookie cutter shark, other types of sharks, or other factors are included. The model also includes fish weight to account for the potential price premiums due to fish size, and fish species to account for the price premium of bigeye tuna. Trip-specific information includes whether the fish was caught during a deep-set or shallow-set trip as the latter targets swordfish; therefore, bigeye and yellowfin are considered bycatch, and the quality could be different from those caught by deep-set trips that target bigeye tuna. Daily market conditions include total daily landings of bigeye tuna and yellowfin tuna and daily visitors to Hawai'i. We used daily visitor arrivals lagged by one day, as this better reflects market conditions. Since the fish auction operates early in the morning, visitor arrivals from the previous day provide a more accurate representation of the potential demand. Foreign imports are included to account for the potential substitution effect that could impact market conditions. Individual seller effects which reflect the potential effect from sellers that produce different quality of fish are also included. Time effects include year effects, week-of-year effects, and day-of-week effects.

The functional form to estimate fish price per lb is specified as follows:

$$P_{it} = SST_j + LENGTH_p + CC + CCDAM + SHARK + DAMAGE + WEIGHT_i + CC \times WEIGHT_i + CCDAM \times WEIGHT_i + SHARK \times WEIGHT_i + DAMAGE \times WEIGHT_i + BIGEYE + TRIP + BIGEYESALE_t + YELLOWFINSALE_t + VISITOR_{t-1} + IMPORT_m + V_k + E_y + E_w + E_d + \varepsilon_{it.} \quad (1)$$

- P_{it} represents the inflation-adjusted price per lb for fish *i* at transaction date *t*.
- SST_j is the average SST at all the hauling locations, where *j* denotes the hauling date.
- $LENGTH_p$ is the number of days between the trip departure date and the fish sale date, where *p* is the trip-level index.
- *CC* = 1 if the fish has three or fewer cookie cutter bites, 0 otherwise.
- *CCDAM* = 1 if the fish has four or more cookie cutter bites, 0 otherwise.
- *SHARK* = 1 if the fish is damaged by a shark other than a cookie cutter shark, 0 otherwise.
- *DAMAGE* = 1 if the fish is damaged by factors other than cookie cutter sharks or other sharks, 0 otherwise.
- $WEIGHT_i$ is the weight (lb) of fish *i*.
- *BIGEYE* = 1 for bigeye tuna, 0 for yellowfin tuna.
- *TRIP* = 1 for shallow-set trip, 0 for deep-set trip.
- $BIGEYESALE_t$ is the daily bigeye sale (lb) at date *t*.
- $YELLOWFINSALE_t$ is the daily yellowfin sale (lb) at date *t*.
- $VISITOR_{t-1}$ is the daily visitor arrivals at date *t-1*.
- $IMPORT_m$ represents the monthly foreign frozen tuna imports to Hawai'i.
- V_k represents the individual seller effects.
- E_y are the annual fixed effects.
- E_w are the week-of-year fixed effects.
- E_d are day-of-week fixed effects.
- ε ***it*** is the error term.

Interaction terms between WEIGHT and the variables CC, CCDAM, SHARK, DAMAGE are included to investigate whether the price effects of shark depredation and other types of damage vary with fish weight. Square terms for the continuous (non-dummy) variables are incorporated to capture potential non-linear relationships with fish prices, with only significant terms retained in the final model. Equation 1 is estimated by ordinary least square (OLS) method with fixed effects. The fixed effects include seller fixed effects, year effects, week-of-year effects, and day-of-week effects. These fixed effects are set up as dummy variables (0 or 1) in the model. To account for potential correlation of error terms at the seller level, clustered standard errors at the seller level are applied in the model estimation.

Data

The fish sales data are from Hawai'i dealer reporting system [38] that records every transaction that occurs in the UFA at Honolulu (UFA data). The UFA records the transaction date, species name, number sold, pounds sold, fish price, revenue, comments on the fish if it is damaged by cookie cutter shark, another type of shark, or other. These records also contain fishing trip information including trip number, vessel name, and fisher ID. The UFA data can be linked with the Hawai'i longline logbook data [39] so that specific fishing trip information is linked with the fish transaction. Trip-specific information in the logbook includes trip departure and return dates, fishing set and haul locations, and trip type (deep-set or shallow-set trip).

Daily SST data are at 5-km horizontal resolution, sourced from NOAA OceanWatch, CoralTemp, v3.1 [40]. The average SST for a trip was calculated using the daily SST matching the begin haul location of an individual set in a fishing trip and taking an average of the matched SSTs for all the hauling locations in a trip. Trip length (LENGTH) is the number of days between the trip departure date recorded in the Hawai'i longline logbook [39] and the fish sale date recorded in the UFA data. Hawai'i daily visitor arrival data is from Hawai'i Department of Business, Economic Development & Tourism (DBEDT) (https://dbedt.hawaii.gov/visitor/daily-passenger-counts/). Foreign imports data are available on a monthly basis from the U.S. Census Bureau and can be accessed on the NOAA website [41]. The monthly imports were merged with the UFA data based on the month of the fish transaction. Table 1 shows the descriptive statistics of fish prices and the covariates used in the model.

Only fresh bigeye tuna and fresh yellowfin tuna were included in the analysis; frozen and smoked fish were excluded. Some fish were sold in lot (a number of fish together), so each data record in this case includes several fish. We cannot identify individual fish quality and size if they were sold in lot, so these fish records were excluded in the analysis. We also exclude observations where the fish price is below $1. Fish priced that low could be owing to factors not accounted for in the price model, such as bad quality due to muscular liquefaction. We consulted with UFA, and they agreed that considering prices lower than $1 as outliers and excluding them is reasonable.

The number of sale records in the UFA data between 2021 and 2023 was 1,005,272, consisting of 59.7 million lb of fish sold, valued at $324.0 million (inflation adjusted to 2023 value). Among the total $324.0 million of fish sold, 62% was bigeye tuna and 19% was yellowfin tuna. When including only cases that meet the criteria for modeling (i.e., bigeye or yellowfin tuna that are non-frozen, non-smoked, sold as a single piece, with fish price of $1 or higher) and excluding records that do not match the logbook data or have unrealistic durations between landed date and sold date, the final sample contains 571,470 sale records, representing 40.8 million lb sold (68% of total lb sold), valued at $257.8 million (80% of total value sold). Fish prices were inflation adjusted to 2023 dollars using Honolulu's all urban-consumers Consumer Price Index (CPI).

Results

The model results are shown in Table 2; only significant variables are displayed. The model fit is good with (degree of freedoms) adjusted R^2 at 0.89. All the coefficients have the expected sign. Fish size effect is positive ($0.09 per lb), and increases at a decreasing rate. Bigeye has a price premium about $0.79 per lb over yellowfin, all other variables being equal. Fish caught during a deep-set trip also produce a price premium over those caught on a shallow-set trip ($0.62). As expected, fish caught during a longer trip generate a lower price (-$0.14 per lb per day), but the rate of decrease diminishes over time (i.e., positive square term). An increase in trip length by 10 days would cause fish price to drop by $1.25 per lb. Changes in market

Table 1. Descriptive statistics of variables.

	Mean	Std. Deviation	Frequency	Distribution
Price per lb (inflation adjusted)	5.76	2.91		
SST (°C)	25.40	1.59		
LENGTH (day)	23.48	4.66		
WEIGHT (lb)	71.34	31.19		
Base (total transactions)	571,470			
BIGEYESALE (lb)	32,432	12,218		
YELLOWFINSALE (lb)	12,078	6,716		
VISITOR (number of people)	26,553	6,633		
Base (number of days with fish sale)	916			
IMPORT (lb)	456,645	234,751		
Base (number of months)	36			
Species				
Bigeye			397,269	69.5%
Yellowfin			174,201	30.5%
Set type				
Deep-set			566,660	99.2%
Shallow-set			4,810	0.8%
Year				
2021			195,965	34.3%
2022			196,350	34.4%
2023			179,155	31.3%
Day of week				
Monday			96,275	16.8%
Tuesday			99,164	17.4%
Wednesday			95,684	16.7%
Thursday			90,236	15.8%
Friday			101,044	17.7%
Saturday			86,993	15.2%
Sunday			2,074	0.4%
Cookie cutter bites 1-3 (CC)			92,274	16.1%
Cookie cutter bites 4+ (CCDAM)			1,172	0.2%
Shark damage (SHARK)			443	0.1%
Other damage (DAMAGE)			4,838	0.8%
Base (total transactions)			571,470	

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condition with 10,000 lb more of bigeye sales in a day translate into -$0.79 per lb, while 10,000 lb more of yellowfin sales translate into -$0.51 per lb. More visitor arrivals translate into higher fish prices at a decreasing rate. An increase of 1,000 daily visitor arrivals translates into a $0.48 increase in fish price. A 10,000 lb increase in monthly foreign tuna imports induces a $0.14 decrease in local fish price.

Implications of climate change on fish price

SST has significant negative effects on fish prices. A one-degree Celsius increase in SST is associated with $0.08 decrease in price per lb. The average SST for a trip ranged from 16.7 °C to 28.4 °C, translating to a $0.96 per lb difference in price. To assess the annual revenue impact of a one-degree Celsius increase in SST, we apply the estimated $0.08 per lb price decrease to

Table 2. Estimated coefficients from the model estimation.

	Parameter estimate	Standard error
SST	−0.0824**	0.0166
LENGTH	−0.1380**	0.0308
LENGTH ^{2}	0.0013*	0.0007
CC	−0.1408**	0.0276
CC × WEIGHT	0.0045**	0.0004
CCDAM	−0.4489**	0.1387
CCDAM × WEIGHT	−0.0053*	0.0021
SHARK	−1.3341**	0.1039
DAMAGE	−0.5267**	0.0934
DAMAGE × WEIGHT	−0.0080**	0.0013
WEIGHT	0.0879**	0.0010
WEIGHT ^{2}	−0.0003**	4.8916E-06
BIGEYE	0.7885**	0.0192
Trip Type (1 = shallow set)	−0.6194**	0.1662
BIGEYESALE	−8.4717E-05**	7.9748E-06
BIGEYESALE ^{2}	6.1057E-10**	9.8818E-11
YELLOWFINSALE	−5.1351E-05**	2.9674E-06
VISITOR	4.8406E-04**	1.7693E-05
VISITOR ^{2}	−8.6376E-09**	4.3649E-10
IMPORT	−1.3659E-06**	1.0363E-07
Seller fixed effects	Included	
Year effects	Included	
Week-of-year effects	Included	
Day-of-week effects	Included	

* p<0.05, ** p<0.01.

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the average annual sales volume of bigeye and yellowfin from 2021 to 2023. This translates to an estimated revenue loss of $1.1 million per year, or 1.3% of annual revenue (Table 3).

In addition to higher SST, climate change has led to a poleward shift in tuna habitat in the North Pacific [23]. Using 30 years of Hawai'i deep-set longline fishery data, Chan [3] estimated that a one-degree Celsius increase in SST corresponded to a 4.2% increase in deep-set longline trip distance. Given an average of 23.5 days between trip departure and fish sale (Table 1), this suggests that a one-degree Celsius SST rise extends trip length by about one day. To assess the annual revenue impact of a one-day increase in trip length, we apply the estimated coefficients for an extra trip day (Table 2) to the average annual sales volume of bigeye and yellowfin from 2021 to 2023. This results in an estimated revenue loss of $1.9 million per year, or 2.2% of annual revenue (Table 3).

Climate-induced reduction in tuna body size could significantly impact both price and revenue. Erauskin-Extramiana et al. [17] projected that by mid-century, the body sizes of bigeye and yellowfin in the western and central Pacific Ocean will decrease by 16% and 15%, respectively. With an average fish weight of 71.3 lb in the sample, this translates to an approximate 11 lb decrease in body size. To estimate the annual revenue impact of this decline, we apply the estimated coefficients for fish size effects (Table 2) to the average annual sales volume of bigeye and yellowfin from 2021 to 2023. This 11 lb reduction in body size is projected to result in a revenue loss of $12.7 million per year, or 14.8% of annual revenue (Table 3).

Daily supply impact

Decreased landings of bigeye and yellowfin negatively affect prices. Using the associate coefficients, we can calculate the price flexibility for bigeye and yellowfin (Table 4). The price flexibility represents the percentage change in price in response to a 1% change in quantity supplied. The price flexibilities for bigeye and yellowfin are both negative and less than one, indicating that price increases/decreases proportionally less than fish supply decreases/increases. This is consistent with the flexibilities found in McConnell & Strand [11] and Pan & Pooley [13] for the Hawai'i tuna market. If the daily supply of tuna decreases due to climate change, the model results indicate that the price of tuna will rise. However, fishers are likely to experience a decline in revenue. This is because the price flexibilities for bigeye and yellowfin are less than one, indicating that the increase in tuna prices will be proportionally smaller than the reduction in supply.

Price and revenue impacts due to cookie cutter shark depredation, other shark depredation, and other damage

The coefficient for CC is negative but the interaction term with fish weight is positive, meaning when fish had minor damage by cookie cutter shark (1–3 bites), the price impact is negative, but the impact becomes smaller for bigger fish. This is reasonable given the small size of cookie cutter bites on tuna (average weight of tuna in sample was 71.3 lb). Using the coefficients for CC and CC × WEIGHT, the cutoff point of weight that has negative price impact is 31 lb, meaning when the tuna is smaller than 31 lb and has 1 to 3 cookie cutter bites, the price impact is negative. But when fish is larger than 31 lb, there is no negative price impact. This differs from the positive interaction terms for CCDAM and DAMAGE with WEIGHT, which indicate that the price impact is greater for larger fish when they experience more cookie cutter bites (4+) or other types of damage. For shark bites, the price impact is the same regardless of fish size, as the interaction term is insignificant.

Using the coefficients for shark depredation and other damage and their interaction terms with WEIGHT (Table 2), the average weight of bigeye (74.78 lb) and yellowfin (63.51 lb), and the average price per lb for bigeye ($6.12) and yellowfin ($4.93) in 2021–2023, Table 5 shows the price and revenue impacts due to shark depredation and other damage. The per lb price impacts for bigeye range between −14% and −22% and between −16% and −27% for yellowfin;

Table 3. Estimated price and revenue effects due to climate change.

	Price effect per lb ($)	Estimated lost revenue per year ($)	Estimated lost revenue (percent of average 2021–2023 tuna revenue) (%)
Increase SST by 1 °C	−0.08	−1,119,203	−1.3%
Increase trip length by 1 day	−0.14	−1,857,579	−2.2%
Decrease body size by 11 lb	−0.93	−12,677,881	−14.8%

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Table 4. Price flexibility for bigeye and yellowfin tunas.

	Estimated coefficient of landings (10,000 lb)	Average daily landings (10,000 lb)	Inflation adjusted average daily price ($)	Price flexibility
Bigeye	−0.85	3.82	6.12	−0.53
Yellowfin	−0.51	1.76	4.93	−0.18

https://doi.org/10.1371/journal.pclm.0000595.t004 the estimated lost revenue ranges between $63 and $100 per individual bigeye, and $50 and $85 per each yellowfin.

The estimated annual revenue lost due to damage (Table 6) is calculated using the per lb price impacts from shark depredation and other damage estimated from the model (Table 2) and applied to the actual weight of all the individual damaged fish in the sample. The estimated percentage lost due to shark depredation and other damage represents 0.2% of total annual tuna revenue.

Conclusion and discussion

Most of the bigeye and yellowfin tuna landed by the Hawai‘i longline fishery are sold at the UFA. As landings are cleared daily, prices fluctuate due to various factors. The Hawai‘i longline fishery is well-known for producing high quality fresh tuna for consumption by both local residents and visitors. Using hedonic price modeling, we discover how various factors affect the price of tuna. These include fish characteristics, daily market conditions, trip-specific information, foreign imports, individual seller effects, and time effects. Unlike other hedonic models for fish price, this study also incorporates the environmental conditions of the fishing trip linked to each individual fish sold, serving as a proxy for fish quality. This highlights the important implications of climate change on fish prices. The model results show a significant negative relationship between SST and tuna prices, indicating that higher SST adversely affects tuna quality, leading to lower prices. Consequently, further increases in SST driven by climate change are likely to result in a decline in tuna prices in the future. In addition, climate change has shifted tuna habitat poleward in the North Pacific [23], which could cause the Hawai‘i longline vessels to travel further from the Honolulu fishing port [3]. Our model results indicate that longer travel distances negatively affect fish prices, suggesting that longer trip lengths impact fish freshness. Another aspect of climate change impact on fish prices could be the reduction of fish body size [17], as the model results show that bigger tuna produce price premiums. Our model results indicate that the projected reduction in body size by mid-century would have significant impacts on tuna price and revenue for the Hawai‘i longline fishery. Climate change could also impact fish prices by affecting the amount of daily landings through

Table 5. Estimated price impacts due to shark depredation and other damage.

	Price discount for average bigeye ($)	Price discount for average yellowfin ($)	Price discount for bigeye per lb (%)	Price discount for yellowfin per lb (%)	Estimated lost revenue per fish: bigeye ($)	Estimated lost revenue per fish: yellowfin ($)
Cookie cutter 4+	−0.85	−0.79	−14%	−16%	−63.48	−50.08
Shark damage	−1.33	−1.33	−22%	−27%	−99.77	−84.73
Other damage	−1.12	−1.03	−18%	−21%	−84.13	−65.72

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Table 6. Estimated lost revenue due to shark depredation and other damage.

	Cookie cutter 1–3 ($)	Cookie cutter 4+ ($)	Shark damage ($)	Other damage ($)	Total damage ($)	Estimated lost revenue (percent of annual tuna revenue) (%)
2021	−2,308	−18,712	−18,565	−101,880	−141,464	−0.2%
2022	−2,491	−18,711	−9,598	−108,891	−139,691	−0.2%
2023	−985	−27,363	−18,220	−101,120	−147,689	−0.2%
Average per year	−1,928	−21,595	−15,461	−103,964	−142,948	−0.2%

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its effects on tuna abundance [18,19], biomass [4,20], catchability [21,22], and spatial distribution [23,24]. If tuna supply declines due to climate change, the model results indicate that prices will rise. However, fishers will be worse off as their revenue will fall since price increases for bigeye and yellowfin are proportionally smaller than supply reductions.

It is noteworthy that the Hawaiʻi deep-set longline fishery has been adapting to the impacts of climate change over the past 20 years by shifting operations northeast to cooler waters further from the main Hawaiian Islands during the summer and moving closer to them in the winter when overall temperatures are lower. This shift in the spatial distribution of fishing efforts could explain the smaller SST effect on tuna prices found in this study compared to Pan and Pooley [13]. During 1994–1996, fishing efforts were concentrated closer to the main Hawaiian Islands, where there were higher SSTs. As a result, reduced fat content in tuna due to warmer waters contributed to the lowest tuna prices being recorded in the summer. In contrast, the spatial redistribution of fishing efforts in 2021–2023 resulted in higher average monthly fish prices in the summer than in the winter (Fig 2). Therefore, the stronger SST-price relationship found by Pan and Pooley [13] during their sampling period is consistent with the higher SSTs and lower prices observed at the time. Over the past 34 years, SST trends in the Hawaiʻi deep-set longline fishing grounds reveal uneven warming rates across different regions (Fig 5). The fishing grounds near the main Hawaiian Islands (15° to 25°N, 180° to 150°W) and those in the northeast (20° to 40°N, 150° to 125°W) exhibit distinct warming patterns, with the northeast experiencing a slightly faster rate of temperature increase. With anticipated higher SST due to climate change, the negative effects on fish quality and prices are likely to persist. With the consistent differences in SST across regions and the faster warming rate in the northeast fishing ground, fishers might have to travel further from the main Hawaiian Islands to cooler waters for better quality of fish. This would result in longer travel time and higher fishing costs. They also need to consider the impact of longer days at sea on fish freshness and fish prices. This could lead to more vessels relocating to the U.S. west

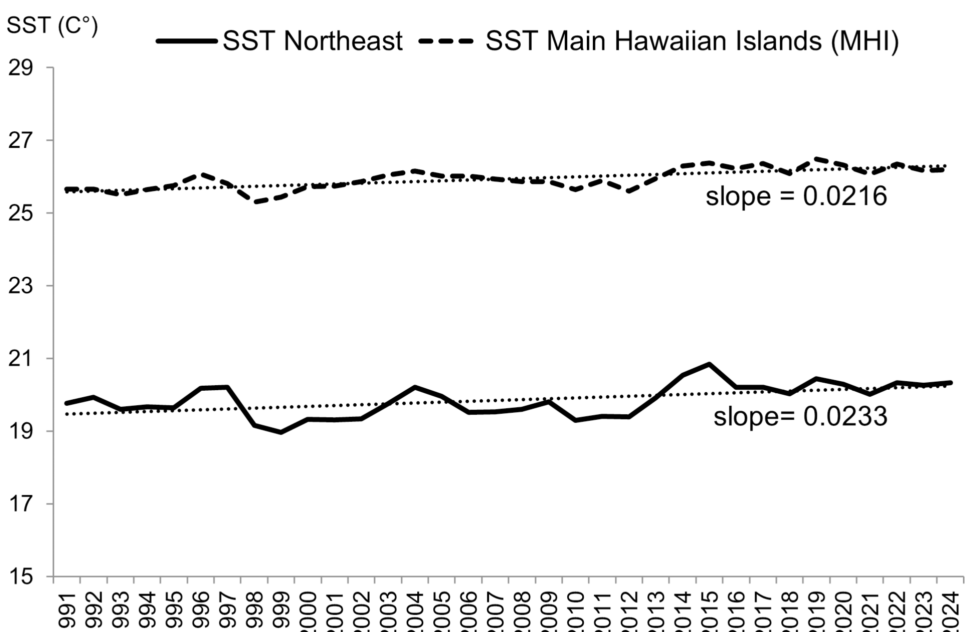

Fig 5. SST trends of Hawaiʻi deep-set longline fishing grounds, 1991 to 2024.

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coast if the distance required to travel to maintain fish quality gets too long and it becomes more economical to do so. Such a shift would have important implications for Hawai'i's food security in the future.

Shark depredation and other damages are persistent phenomena that significantly impact the price of individual fish. Although the incidences were low (except for minor cookie cutter shark damage), the increasing trend in recent years (Fig 3 and Fig 4) is a concern for the fishing industry. This study estimates that the revenue impact on the fishing industry was less than $150,000 per year, equivalent to approximately 0.2% of the annual tuna revenue. It is important to note that climate change may alter the spatial distribution of sharks by changing their suitable habitats [42–45]. Consequently, shark depredation in the Hawai'i longline fishery could be affected by climate change, making future incidence and vessel revenue impact uncertain. It is important to note that there may be instances where fish quality was so poor due to shark or other depredation that it rendered them unsalable at the market. The model in this study is not able to evaluate this type of revenue loss.

The model results from this study indicate that climate change could impact Hawai'i tuna prices through various channels. It is crucial to understand these relationships and their implications for the economic condition of fisheries, fishing operations, seafood markets, and consumer demand. Although this study is limited to the most recent three years of data, this period reflects a more stable market condition, post-pandemic. Additionally, the significant SST variations in the sample data, driven by the large spatial distribution of fishing efforts, provide a robust representation of SST changes, making them suitable for drawing climate change inferences. This study can be integrated with climate and ecosystem predictions for the Hawai'i longline fishing grounds to predict vessel responses to climate change, taking into consideration the price and revenue implications of these behavior shifts. This comprehensive approach enhances understanding of climate change impacts on fisheries and seafood security, helping fisheries management develop informed policies for future sustainability.

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References

1. National Marine Fisheries Service. Fisheries of the United States; 2024 [cited 2025 Jan 29]. Database: top US ports [Internet]. Available from: https://www.fisheries.noaa.gov/foss/f?p=215:11:11713400474246
2. Geslani C, Loke M, Takenaka B, Leung P. Hawaii's seafood consumption and its supply sources. Honolulu: University of Hawaii Joint Research Institute for Marine and Atmospheric Research, SOEST 12-01, JIMAR Contribution 12-379. 2012, 1–26.
3. Chan HL. How climate change and climate variability affected trip distance of a commercial fishery. PLOS Clim. 2023;2(2):e0000143. https://doi.org/10.1371/journal.pclm.0000143
4. Woodworth-Jefcoats PA, Blanchard JL, Drazen JC. Relative Impacts of simultaneous stressors on a pelagic marine ecosystem. Front Mar Sci. 2019;6:383. https://doi.org/10.3389/fmars.2019.00383
5. Gilman E, Chaloupka M, Read A, Dalzell P, Holetschek J, Curtice C. Hawaii longline tuna fishery temporal trends in standardized catch rates and length distributions and effects on pelagic and seamount ecosystems. Aquatic Conservation. 2012;22(4):446–88. https://doi.org/10.1002/aqc.2237
6. Woodworth-Jefcoats PA, Polovina JJ, Drazen JC. Synergy among oceanographic variability, fishery expansion, and longline catch composition in the central North Pacific Ocean. Fishery Bulletin. 2018;116(3–4):228–39. https://doi.org/10.7755/FB.116.3-4.2
7. Forney KA, Kobayashi DR, Johnston DW, Marchetti JA, Marsik MG. What's the catch? Patterns of cetacean bycatch and depredation in Hawaii-based pelagic longline fisheries. Marine Ecology. 2011;32(3):380–91. https://doi.org/10.1111/j.1439-0485.2011.00454.x
8. Gilman E, Clarke S, Brothers N, Alfaro-Shigueto J, Mandelman J, Mangel J, et al. Shark interactions in pelagic longline fisheries. Marine Policy. 2008;32(1):1–18. https://doi.org/10.1016/j.marpol.2007.05.001
9. Huang H, Leung P. Testing for market linkages between Hawaii and Japan's tuna markets. Fisheries Research. 2011;109(2–3):351–9. https://doi.org/10.1016/j.fishres.2011.03.004
10. Kleiber D, Iwane M, Kamikawa K, Leong K, Hospital J. Pacific Islands region fisheries and COVID-19: impacts and adaptations. NOAA Tech Memo NMFS-PIFSC. 2022;130:1–36.
11. McConnell KE, Strand IE. Hedonic prices for fish: tuna prices in Hawaii. Am J Agric Econ. 2000;82(1):133–44.
12. Pethybridge HR, Parrish CC, Morrongiello J, Young JW, Farley JH, Gunasekera RM, et al. Spatial Patterns and temperature predictions of tuna fatty acids: tracing essential nutrients and changes in primary producers. PLoS One. 2015;10(7):e0131598. https://doi.org/10.1371/journal.pone.0131598 PMID: 26135308
13. Pan M, Pooley S. Tuna price in relation to economic factors and sea surface temperature in fresh tuna market. IIFET 2004 Japan Proceedings. 2004;1–12.
14. Boggs C. Depth, capture time, and hooked longevity of longline-caught pelagic fish: timing bites of fish with chips. Fish Bulletin. 1992;90(4):642–58.
15. Carlisle AB, Allan EA, Kim SL, Meyer L, Port J, Scherrer S, et al. Integrating multiple chemical tracers to elucidate the diet and habitat of Cookiecutter Sharks. Sci Rep. 2021;11(1):11809. https://doi.org/10.1038/s41598-021-89903-z PMID: 34083578
16. Papastamatiou YP, Wetherbee BM, O'Sullivan J, Goodmanlowe GD, Lowe CG. Foraging ecology of Cookiecutter Sharks (Isistius brasiliensis) on pelagic fishes in Hawaii, inferred from prey bite wounds. Environ Biol Fish. 2010;88(4):361–8. https://doi.org/10.1007/s10641-010-9649-2
17. Erauskin-Extramiana M, Chust G, Arrizabalaga H, Cheung WWL, Santiago J, Merino G, et al. Implications for the global tuna fishing industry of climate change-driven alterations in productivity and body sizes. Global and Planetary Change. 2023;222:104055. https://doi.org/10.1016/j.gloplacha.2023.104055
18. Lehodey P, Senina I, Sibert J, Bopp L, Calmettes B, Hampton J, et al. Preliminary forecasts of Pacific bigeye tuna population trends under the A2 IPCC scenario. Progress in Oceanography. 2010;86(1–2):302–15. https://doi.org/10.1016/j.pocean.2010.04.021
19. Senina I, Lehodey P, Smith N, Hampton J, Reid C, Bell J. Impact of climate change on tropical Pacific tuna and their fisheries in Pacific Islands waters and high seas areas. Final

Report (CI-3) for SAN 6003922. 2018. Available from: https://www.semanticscholar.org/paper/Impact-of-climate-change-on-tropical-tuna-species/f7adad51b675f8e8e6492681b4c99e83de4cf1b8

20. Bell JD, Senina I, Adams T, Aumont O, Calmettes B, Clark S, et al. Pathways to sustaining tuna-dependent Pacific Island economies during climate change. Nat Sustain. 2021;4(10):900–10. https://doi.org/10.1038/s41893-021-00745-z

21. Lan K-W, Wu Y-L, Chen L-C, Naimullah M, Lin T-H. Effects of climate change in marine ecosystems based on the spatiotemporal age structure of top predators: a case study of bigeye tuna in the pacific ocean. Front Mar Sci. 2021;8:1–13. https://doi.org/10.3389/fmars.2021.614594

22. Williams P, Ruaia T. Overview of tuna fisheries in the western and central Pacific Ocean, including economic conditions – 2020. 17th regular session of the scientific committee, Western and Central Pacific Fisheries Commission, 11–19 August 2021. 2021: 1–66. Available from: https://meetings.wcpfc.int/node/12527

23. Erauskin-Extramiana M, Arrizabalaga H, Hobday AJ, Cabré A, Ibaibarriaga L, Arregui I, et al. Large-scale distribution of tuna species in a warming ocean. Glob Chang Biol. 2019;25(6):2043–60. https://doi.org/10.1111/gcb.14630 PMID: 30908786

24. Monllor-Hurtado A, Pennino MG, Sanchez-Lizaso JL. Shift in tuna catches due to ocean warming. PLoS One. 2017;12(6):e0178196. https://doi.org/10.1371/journal.pone.0178196 PMID: 28591205

25. Abidoye RB, Chan APC. Critical review of hedonic pricing model application in property price appraisal: A case of Nigeria. Int J Sustain Built Environ. 2017;6(1):250–9. https://doi.org/10.1016/j.ijsbe.2017.02.007

26. Chin T, Chau K. A critical review of literature on the hedonic price model. Int J Hous Appl. 2003;27(2):145–65.

27. Espinet JM, Saez M, Coenders G, Fluvia M. Effect on prices of the attributes of holiday hotels: a hedonic prices approach. Tour Econ. 2003;9(2):165–177. https://doi.org/10.1086/710052

28. Francke M, Van de Minne A. Modeling unobserved heterogeneity in hedonic price models. Real Estate Econ. 2021;49(4):1315–39.

29. Brasington DM, Hite D. Demand for environmental quality: a spatial hedonic analysis. Reg Sci Urban Econ. 2005;35(1):57–82. https://doi.org/10.1016/j.regsciurbeco.2003.09.001

30. Łaszkiewicz E, Czembrowski P, Kronenberg J. Can proximity to urban green spaces be considered a luxury? Classifying a non-tradable good with the use of hedonic pricing method. Ecol Econ. 2019;161:237–47. https://doi.org/10.1016/j.ecolecon.2019.03.025

31. Lipton D, Lew D, Wallmo K, Wiley P, Dvarskas A. The evolution of non-market valuation of U.S. coastal and marine resources. J Ocean Coast Econ. 2014;2014(1):Article 6.

32. Asche F, Bronnmann J, Cojocaru AL. The value of responsibly farmed fish: A hedonic price study of ASC-certified whitefish. Ecol Econ. 2021;188107135. https://doi.org/10.1016/j.ecolecon.2021.107135

33. Hammarlund C. The big, the bad, and the average: hedonic prices and inverse demand for baltic Cod. Mar Res Econ. 2015;30(2):157–77. https://doi.org/10.1086/679972

34. Hukom V, Nielsen M, Ankamah-Yeboah I, Nielsen R. A hedonic price study on warm- and cold-water shrimp in danish retail sale. Aquac Econ Managment. 2019;24(1):1–19. https://doi.org/10.1080/13657305.2019.1669228

35. Lee M-Y. Hedonic pricing of Atlantic Cod: effects of size, freshness, and gear. Mar Res Econ. 2014;29(3):259–77. https://doi.org/10.1086/677769

36. Pettersen IK, Asche F. Hedonic Price Analysis of ex-vessel Cod MARKETS in Norway. Mar Res Econ. 2020;35(4):343–59. https://doi.org/10.1086/710052

37. Sogn-Grundvåg G, Zhang D, Iversen A. Large buyers at a fish auction: The case of the Norwegian pelagic auction. Mar Policy. 2019;104:232–8. https://doi.org/10.1016/j.marpol.2018.06.011

38. Pacific Islands Fisheries Science Center. Hawaii DAR Commercial Purchases. 2024 [cited 2024 Jan 28]. Database: InPort [Internet]. Available from: https://www.fisheries.noaa.gov/inport/item/5610

39. PIFSC Fisheries Monitoring and Analysis Program. Hawaii Longline Logbook. 2024 [cited 2024 Jan 28]. Database: InPort [Internet]. Available from: https://www.fisheries.noaa.gov/inport/item/2721

40. NOAA Coral Reef Watch. NOAA Coral Reef Watch Sea Surface Temperature CoralTemp v3.1 Monthly Data for North Pacific Ocean. 2024 [cited 2024 Jan 3]. Database: ERDDAP [Internet]. Available from: https://oceanwatch.pifsc.noaa.gov/erddap/griddap/CRW_sst_v3_1_monthly.html

41. National Marine Fisheries Service. Commercial Fisheries: Foreign Trade. 2024 [cited 2024 Nov 29]. Database: U.S. foreign trade [Internet]. Available from: http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/

42. Bartes S, Braccini M. Potential expansion in the spatial distribution of subtropical and temperate west Australian sharks. J Fish Biol. 2021;99(4):1503–6. https://doi.org/10.1111/jfb.14822 PMID: 34085705

43. Birkmanis CA, Freer JJ, Simmons LW, Partridge JC, Sequeira AMM. Future distribution of suitable habitat for pelagic sharks in australia under climate change models. Front Mar Sci. 2020;7:1–11. https://doi.org/10.3389/fmars.2020.00570

44. Cheung WWL, Meeuwig JJ, Feng M, Harvey E, Lam VWY, Langlois T, et al. Climate-change induced tropicalisation of marine communities in Western Australia. Mar Freshwater Res. 2012;63(5):415. https://doi.org/10.1071/mf11205

45. Hazen E, Jorgensen S, Rykaczewski R, Bograd S, Foley D, Jonsen I. Predicted habitat shifts of Pacific top predators in a changing climate. Nature Climate Change. 2013;3(3):234–8.