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Measuring Productivity in a Shared Stock Fishery: A Case Study of the Hawaii Longline Fishery

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ABSTRACT

Fisheries productivity is the result of many factors, including endogenous and exogenous elements, such as regulation and stock condition. Understanding changes in productivity and the factors affecting that change is important to fishery management and a sustainable fishing industry. However, no study has been conducted to measure productivity change in the Hawaii longline fishery, the largest fresh bigeye tuna and swordfish producer in the United Stated. Using a Lowe productivity index, productivity change in the Hawaii longline fleet between 2000 and 2012 is measured in this study. In addition, a biomass quantity index is constructed to disentangle biomass impacts in a pelagic environment in order to arrive at an "unbiased" productivity metric. This is particularly important in the Hawaii longline fishery where catches rely mostly on transboundary (shared) stocks with little control on the total amount of extraction. As resource depletion of the transboundary stocks occurs, productivity loss may follow if less output is obtained from the same input usage, or more inputs are used to extract the same catch level from the fishery. Finally, the study compares productivity change under different fishing technologies.

1. Introduction

Fisheries productivity is the result of many endogenous factors, such as fishing gear improvement, technical change for both electronics and engine power, and exogenous factors such as regulatory and stock conditions. Understanding the impact of both types of change on productivity is important to fisheries management. While a domestic fishery may enjoy productivity gains from output control policies (such as catch shares) that lead to an ending of the "race to fish" and an increase of fish stock abundance [1], it may not be the case for a fishery that operates in an open ocean where fishermen face competition from foreign fisheries or different fishing gear that harvest the fish from the same stocks. This paper aims to measure productivity change in the Hawaii longline fishery where catches are mostly obtained from transboundary stocks, and examines the impacts of key elements, including stock conditions and fishing technology (e.g., species targeted), on productivity change. This information can contribute to fisheries management and a more sustainable fishery industry.

2. Fishery synopsis

The Hawaii longline fishery, the largest fishery managed under the Western Pacific Fisheries Management Council, operates in the North Pacific Ocean by harvesting fish inside and outside of the exclusive economic zone (EEZ) of the United States. Between 2002 and 2012 there were 100 to 129 active vessels operating in this fishery, completing between 1,162 and 1,380 fishing trips annually, and generating revenues ranging from $37 to $92 million per year [2]. Currently, the Hawaii longline fishery is managed under a limited-entry program with 164 permits, which are transferable, and a total allowable catch (quota) for bigeye tuna. The bigeye tuna quota was imposed on the fishery by two Regional Fisheries Management Organizations (RFMOs), the Western and Central Pacific Fisheries Commission (WCPFC), and the Inter-American Tropical Tuna Commission (IATTC), as a result of the overfishing status of bigeye tuna in the North Pacific Ocean [3].

Vessels in the Hawaii longline fishery can conduct two types of fishing by adjusting the number of hooks on a fishing line and setting the lines and hooks to different depths in the water column. Deep-set lines target bigeye tuna and shallow-set lines target swordfish. Switching fishing targets during a trip is technically feasible. In practice, fishermen cannot set gear to target swordfish if they do not report that intent to the National Marine Fisheries Service (NMFS) prior to starting the trip because any swordfish-targeted trips require 100% observer coverage. Currently, the

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majority of the fishing vessels of the Hawaii longline fishery target bigeye tuna. About 15% of vessels target swordfish during spring and summer seasons and target bigeye tuna during the rest of the year (with one or two vessels fishing for swordfish year-around), while the other 85% of the vessels target bigeye tuna year-round. In 2012, bigeye tuna alone accounted for 67% of total revenue at $62 million for the entire fleet, while swordfish accounted for 7% of total revenue at $6 million, and other pelagic species (including yellowfin tuna, albacore tuna, moonfish, mahimahi, and pomfret) contributed 26% to total revenue [2]. All the species caught by the Hawaii longline fleet are both highly migratory and shared with other countries fishing in the North and central Pacific Ocean. While the Hawaii longline fishery was responsible for the majority of total U.S. bigeye tuna and swordfish landings, the total fish caught by all U.S. fleets comprised only a small portion of the total catch for the two species from the North Pacific. In 2012, U.S. fishermen harvested 7,534 metric tons (mt) of bigeye tuna and 1,477 mt of swordfish, approximately 4% and 6% respectively of the total catch from the North and central Pacific [4].

The Hawaii longline fishery is heavily regulated. Pan [5] provided a detailed description of the main management tools/regulations implemented in the fishery. A brief summary of the management tools imposed on the fishery during the period, 2001–2012, covered in this study is provided in Table 1.

In addition to regulatory conditions, productivity of the Hawaii longline fishery may be influenced by other exogenous conditions. An important exogenous factor, the Hawaii longline fishery faces strong competition from foreign longline fleets and purse seiners that target the same species from a common pool resource [5]. These stocks have been subjected to overfishing for more than a decade [3]. Although the bigeye tuna catch by the longline fleets in the western and central Pacific Ocean (WCPO) declined in recent years due to imposed conservation measures, the total bigeye catch still went up because bigeye catches by purse seine fisheries increased in the same region and thus overfishing has not been halted [6]. The Western and Central Pacific Fisheries Commission (WCPFC) called for further reduction in bigeye catch limits. The total available catch to the Hawaii longline fleet declined from the current level of 3,763 mt to 3,554 mt for both 2015 and 2016, and will further decline to 3,345 mt for 2017 [3].

Another exogenous factor is regulations intended to protect endangered species. For example, a study by [7] shows that fishery closures during 2000 to 2004 and sea turtle caps instituted in the Hawaii swordfish longline fishery in 2004 to protect endangered sea turtle species led to spillover effects. The foregone production from the Hawaii longline fishery was replaced by foreign fleets that began fishing the same grounds where the Hawaii vessels used to fish prior to enforcement of the regulations.

Third, a vast marine protected area, named the Papahānaumokuākea Marine National Monument, was established by U.S. President George W. Bush on June 15, 2006, thus reducing the size of the fishing grounds in the EEZ that was once available to the Hawaii longline fishery [9]. The monument encompasses an area of approximately 139,793 square miles (362,061 km^2) in the Northwestern Hawaiian Archipelago. This amounts to 23% of the total Hawaiian Archipelago EEZ where no fishing activities are permitted. Historically, 9% of the catch of bigeye and 17% of swordfish came from the EEZ of this Northwestern Hawaiian Archipelago area [8]. In addition, the False Killer Whale Take Reduction Team [10] established a “Southern Exclusion Zone” (SEZ) south of the main Hawaiian Islands to prevent fishery interaction (bycatch) with false killer whales in 2012. Once the deep-set longline fishery reaches a specific level of observed false killer whale bycatch, the area will be closed for deep-set fishing.

Catch data show that Hawaii longline fishing increased its dependence on resources outside the U.S. EEZ. For example, in 2012, of the total bigeye tuna landed (kept) by the Hawaii longline fishery, 65% were caught outside of the U.S. EEZ (including the Hawaiian Islands EEZ and the Pacific Remote Islands Area EEZ), which is a 21% increase compared to 44% in 2002 [6].

Cost-earnings studies show the Hawaii longline fishery garners a small profit margin, which has declined as operating costs have increased in recent years [5]. Because operating costs increased, small productivity gains in fishing industries can be important for maintaining or increasing profit levels for individual vessels. Therefore, it is important to understand productivity changes and factors that may affect the changes. The objective of this study is to measure productivity change in the Hawaii longline fishery over time and to distinguish the effect of technical efficiency (the rate of inputs converted into outputs) and the effects of resource abundance on that productivity.

Although several economic studies have been conducted on the productivity of the Hawaii longline fishery [11,12,13], all of the previous studies focused on examining the productivity performance in a static setting using a single year of data. Little attention has been given to measuring productivity change in the fishery over time. Moreover, biomass was not considered as a variable in these previous studies. Productivity measures without considering the impact of biomass can be biased [14], as biomass changes may influence fishery industry productivity, often resulting in higher or lower outputs for the same amount of inputs. This paper provides the first comprehensive estimate of productivity changes in the Hawaii longline fishery where catches are mostly from transboundary stocks.

Table 1
Hawaii longline fishery management tools employed during 2001 to 2012.

Date	Management tools employed	Related fishery
April 2001	Partial closure of certain waters in November 1999, and a complete shutdown of the swordfish fishery in April 2001 due to the concerns of turtle interactions with the fishery	Swordfish
April 2004	Reopening of swordfish fishing with a series of regulations (100% observed, cap of fishing effort, caps of sea turtles, bait type, gear modifications, etc.)	Swordfish
2004	Bigeye total allowable catch (TAC) in EPO imposed by the IATTC beginning in 2004 and it only applied to vessels that were longer than 24 m. The annual TAC was 150 mt from 2004 to 2006, and 500 mt after 2007 to present	Bigeye tuna
Jun 2006	A vast marine protected area, named Pahānaumokuākea Marine National Monument, was established in North Western Hawaiian Islands	Swordfish and bigeye
2009–2010	Bigeye TAC imposed in WCPO in 2009 and the annual TAC was 3763 mt. The bigeye fishery was closed for two days before New Year in 2009 and closed on November 22 when the catch limit was reached	Bigeye tuna
2011–2012	The Hawaii fishery had no effective bigeye TAC in 2011 or 2012 because the Hawaii fishery was able to attribute a part of the bigeye catch to United States Pacific territories. Also catches by the dual-permitted vessels with the territories do not count against the United States TAC	Bigeye tuna
November 2012	NMFS revised the sea turtle catch caps (limits) for leatherback turtles from 16 to 26, and for loggerhead turtles from 17 to 34	Swordfish
December 2012	Established a “Southern Exclusion Zone” (SEZ) south of the Main Hawaiian Islands to prevent fishery interaction (bycatch) with False Killer Whales	Bigeye tuna

3. Methodology

In fisheries, productivity is defined as the relationship between the quantity of fish produced and the amount of inputs used to harvest the fish [1]. Thus, productivity change can be measured as the ratio of the change in output (fish) produced to the change in inputs used to achieve the outputs. Productivity change is the quantity component of profitability change, meaning it measures the change in the ratio of outputs produced by the firm, to the change in inputs used to produce the outputs, compared to a base year or previous period. The Lowe index was selected for this study because it was identified as an index which had important properties from index number theory [15], and could be easily constructed using standard spreadsheet software. The Lowe index measures multi-factor productivity (MFP), meaning it is constructed using multiple outputs and multiple inputs. O'Donnell [15] recently demonstrated that the Lowe index satisfies all economically-relevant axioms from index number theory. Recently, NOAA fisheries used the Lowe index to measure productivity change across all United States catch share fisheries, to evaluate whether catch share management leads to an improvement of productivity, as expected. Since this study uses the same analytical approach, a detailed treatment of the Lowe index is not repeated herein but can be found in [1].

There are several advantages in constructing the Lowe index to measure productivity change in fisheries. First, the Lowe index is a 'basket type' index, and can include multiple outputs and inputs, which is usually the situation for fishing vessels that typically land a mixture of species using several different inputs. Secondly, the output and input indices are constructed using fixed prices for each input or output in the basket. This means that changing prices do not influence the productivity measure. Additionally, prices do not have to come from the period under study, which is an advantage when price data are not routinely collected. In fisheries, regular collection of price data particularly for input prices is often an issue. Finally, the index is easy to construct using readily available spreadsheet programs, and the measure of productivity change can be made at the vessel, fleet, or fishery level. The ease of constructing the index is attractive when compared to an index such as the Malmquist index (MI) [16,17]. Although the MI only needs data on quantities, and no price data, it requires running four different linear programming models to construct the index, a large number of observations, and often balanced panel data. For this fishery, the fleet size varies over time with vessels entering and exiting the fishery each year [18]. Additionally, a large number of vessels exited after a regulation that banned swordfish harvesting in the summer of 2000, only to return in late 2004 after the fishery reopened. Therefore, to form a balanced panel data across long periods of time in the fishery would exclude a significant amount of observations. The Lowe index as constructed here is an aggregated index calculated at the fishery level (aggregation occurs over all vessels) and avoids computational problems associated with changes in fleet size over time [1].

Finally, biomass data is used to calculate a separate biomass index which is used to adjust the productivity indices to yield a measure of 'unbiased' productivity. In the case of a fishery, the traditional productivity metric of output/input will be biased unless the influence of biomass is separated from the index [19]. To adjust the "biased" productivity measure, [1] developed a "Lowe" biomass index, assuming that greater biomass will produce higher outputs for a given level of inputs than a smaller biomass. This study uses adult biomass to construct the biomass index since catchability may have a closer relationship with adult biomass compared to biomass in general. For multiple species fisheries, the Lowe biomass index is constructed by using the biomass and the share value of landings of each species where the value of all shares sums to 1.

In this study, the Lowe index is constructed in the following steps: 1) Define inputs and outputs relevant to the fishery; 2) Estimate input and output quantities and choose a standardized price (fixed price) for each input and output; 3) Calculate aggregated input and output value at the vessel level and fleet-wide on an annual basis; 4) Select a base year against which productivity change is measured; 5) Calculate the Lowe input index, which is the ratio of annual aggregated input value in a year to the annual aggregated input value of the base year; and the Lowe output index, which is the ratio of fleet-wide annual aggregated output value in a year to the fleet-wide annual aggregated output value of the base year); 6) Calculate the Lowe productivity change index, which is the ratio of the Lowe output index to the Lowe input index; and (7) Adjust by the biomass index to yield a value of biomass-adjusted productivity.

4. Data

The definition of inputs and outputs relevant to the fishing industry is consistent with the general production function

$$Y = F(L, K; B)$$

where Y denotes total output, L is the labor input, K is the capital input, and B represents the biomass condition. For any given combination of labor and capital, output is conditional on biomass denoted as B. Thus to construct the Lowe index for this study data were needed for both quantities and prices for outputs and inputs and for biomass.

4.1. Output Y

The value of catches is defined as the output Y in this study. Catches in the Hawaii longline fishery typically feature multiple species that receive different market prices. The catches are classified into three species groups, including bigeye tuna, swordfish, and other species. The targeted species are separated from the rest of the species because bigeye tuna and swordfish prices are usually higher than the other species and they are the main catches of the fishery. Inflation-adjusted prices ($2010) for the three species were generated based on prices received by individual vessels included in the study from the years 2005–2012. The price for bigeye, swordfish, and the others are respectively $322.23, $373.21, and $68.78 per fish. The total number of fish was the number of fish recorded in the mandatory fishermen's logbooks submitted to the National Marine Fisheries Service. Multiplying the aggregate quantities by the fixed output prices yields the aggregated value of output for the years 2002–2012 shown in the third column of Table 2. The last (fifth) column of Table 2 represents the total number of vessels in the aggregations. While the study intended to include all active vessels, only a few vessels (ranging from 5 to zero vessels in each individual year) without complete input or output data were excluded from the study.

4.2. Capital (K)

Capital (K) as an input needs both a measure of the quantity of capital, and a price for the capital input, which is measured in this study as "user cost". A fishing vessel is the single capital component used here. Generally, the capital value is the average of the beginning and ending book value for the asset (vessel). However, those types of detailed data were unavailable. Using a median price of a sample of advertisements from 10 steel hulled trawl vessels, the capital value for each vessel was set at $1,571 per foot of vessel length times the vessel

Table 2
Output and input in the Hawaii longline fishery (all trips).

Year	Output*	Labor*	Capital*	Total Input*	No. of Vessels
2002	55,302,518	15,383,517	1,403,270	16,786,786	97
2003	49,025,268	15,756,020	1,567,432	17,323,453	107
2004	63,556,533	17,991,699	1,801,623	19,793,321	123
2005	63,875,621	19,892,798	1,807,597	21,700,395	123
2006	58,269,138	20,502,387	1,873,628	22,376,014	127
2007	72,754,358	23,124,369	1,912,712	25,037,081	129
2008	73,797,815	23,437,290	1,920,916	25,358,206	128
2009	61,003,297	24,423,893	1,899,901	26,323,794	126
2010	67,710,360	24,077,553	1,866,560	25,944,113	123
2011	75,273,686	25,135,627	1,922,241	27,057,869	127
2012	77,943,490	27,015,628	1,937,955	28,953,583	129

* Data reported in 2010 are constant dollars using the GDP implicit price deflator.

length.[1] The annual user cost of capital (price) is made up of three components. The first reflects a price that must be paid to the owner of an asset to prevent it from being sold (opportunity cost); the second component reflects depreciation and, the third component is re-investment in the asset [1]. Since information about re-investment is not available in the Hawaii longline fishery, only depreciation was included. The opportunity cost of capital is measured by the rate on BAA rated bonds. Depreciation was set at 6% of vessel value based on rates established by the Bureau of Economic Analysis (BEA). The aggregated user cost of capital for 2002–2012 is presented in the third column of Table 2.

4.3. Labor (L)

Time-series data on labor costs for individual vessels were not available. Labor (L) cost was estimated by the crew size reported on mandatory logbooks multiplied by number of days at sea, and by a daily wage per crew ($/day), following the approach by [1]. The price for labor was estimated by the average hourly earnings of production and nonsupervisory employees, which was $18.21 for 2005 (the base year of the study)[2]. The hourly wage was multiplied by 8 hours to convert to a daily rate, as the daily opportunity cost of crew labor. The aggregated labor cost for 2002–2012 is presented in the second column of Table 2.

4.4. Biomass index (B)

The biomass index is a Lowe quantity index and is constructed in the same manner as the output and index quantity indices described above, with the exception that the base year values are contained in the numerator. This is done to maintain the relationship between biomass adjusted (BA) and unadjusted productivity (BU) in any time period. In mathematical form, the relationship is as follows [1]:

$$MFP_{BU} = MFP_{BA} * B$$

where B is a biomass adjustment factor. Solving for MFP_{BA} yields:

$$MFP_{BA} = MFP_{BU}/B$$

Since we are interested in productivity change, biomass-adjusted productivity change between any two periods, such as time 0 and time t, $\frac{MFP_{BA}^t}{MFP_{BA}^0}$ is constructed as:

$$\frac{MFP_{BA}^t}{MFP_{BA}^0} = \frac{MFP^t/B^t}{MFP^0/B^0}$$

Simplifying, and re-arranging terms yields:

$$\frac{MFP_{BA}^t}{MFP_{BA}^0} = \frac{MFP_B^t}{MFP_B^0} * \frac{B^0}{B^t}$$

Since both left and right-hand side terms can be expressed as index numbers, this yields: $MFP_{BA} = MFP_B * BI$, where all three terms signify index numbers, with BI meaning biomass index. This can also be thought of as an unadjusted productivity index normalized by a biomass index.

In order to construct the biomass index, biomass quantities and prices are needed. Data for annual estimates of adult biomass in mt were obtained from bigeye and swordfish stock assessments documents [20] and [21] respectively. The sum of bigeye biomass from regions 2 and 4 was used in this study as bigeye biomass stock since these stock areas correspond to where the Hawaii longline fleet operates. The swordfish stock biomass for the western and central Pacific presented in the stock assessment [21] was used. “Prices” for the Lowe biomass index for multiple species were calculated as the value shares of each species in 2005 (bigeye equals 0.63, swordfish equals 0.09, and “others” equals 0.28). Multiplying “prices” by biomass quantities of bigeye and swordfish from the stock assessments yields an aggregate value for biomass in each year, while assuming the stock condition for the other species does not change. Because of the way the biomass index is constructed, an increase in biomass between the baseline period (base year) and any other year is represented by an index value below 1.00, while a biomass index value above 1.00 indicates a decrease in biomass between the base year and any other year.

5. Results

5.1. Results for all swordfish and tuna trips

The Lowe input index for a year was the aggregate inputs for the year divided by the aggregate inputs for the base year. Because the Lowe index is transitive, the choice of a base year does not affect change between any two years in the index [1]. The base year was set as 2005 in this study because it was the first year when swordfish fishing operated for the entire year after it was closed in 2000 and reopened at the end of 2004. Thus, base year data contained both swordfish and tuna fishing activities. An input index value above 1.00 in a year means that inputs in that particular year were higher than that in 2005. Similarly, an output index value above 1.00 in a year means that output for that particular year was higher than that in 2005. The Lowe productivity index is the ratio of the output quantity index to the input quantity index. If an index value is above 1.00 it means that productivity growth is positive and the fishery is getting more output from a given level of inputs, compared to 2005. However, if the index value is below 1.00, the opposite is true.

The unadjusted Lowe productivity index shows a declining trend since 2005 (Table 3). Between 2006 and 2012 all index values were less than 1.00. Prior to 2005, the mean, unadjusted, productivity index for the Hawaii longline fishery was 1.06, and after 2005 it was 0.91. The unadjusted productivity indices were then adjusted by the biomass index (Table 3). As seen, the biomass indices from 2007 to 2012 have a value more than 1.00, signaling a decrease in fish resources for the Hawaii longline fishery during the period 2007–2012. After adjusting for the biomass impact, the biomass adjusted Lowe productivity index shows a different trend (Fig. 1). Between 2002 and 2009, the unadjusted and biomass

[1] Prices paid for steel hulled fishing vessels obtained from http://www.oceanmarine.com accessed May 28, 2013.
[2] Wages rates obtained from http://alfred.stlouisfed.org/series?seid=CEU0500000008&cid=32306.

Table 3
Output and input in the Hawaii longline fishery for all trips.

Year	Output Index	Input Index	Biomass Un-adjusted Lowe Index	Biomass Index	Biomass Ad-justed Lowe Index
2002	0.87	0.77	1.12	0.99	1.10
2003	0.77	0.80	0.96	1.08	1.04
2004	1.00	0.91	1.09	0.99	1.08
2005	1.00	1.00	1.00	1.00	1.00
2006	0.91	1.03	0.88	0.97	0.85
2007	1.14	1.15	0.99	1.00	0.99
2008	1.16	1.17	0.99	1.01	1.00
2009	0.96	1.21	0.79	1.05	0.83
2010	1.06	1.20	0.89	1.09	0.97
2011	1.18	1.25	0.95	1.18	1.11
2012	1.22	1.33	0.91	1.27	1.16

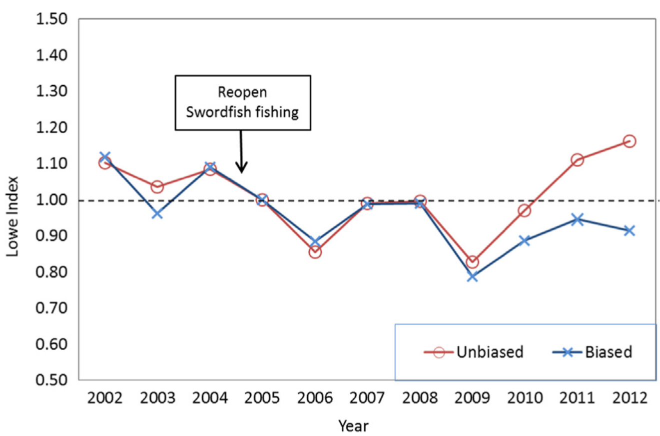

Fig. 1. Adjusted and unadjusted biased and unbiased Lowe index for all trips (base year=2005).

adjusted indices tracked each other quite closely, but after 2009 they diverged. The adjusted productivity leapt from its lowest point of 0.83 in 2009 and moved upward to 1.11 in 2011 and 1.16 in 2012, implying that productivity was 11% and 16% greater in 2011 and 2012, respectively than in the base time period. This suggests an improvement of productivity of the fishery in the face of a declining trend in biomass. Without making this adjustment to the original productivity measure, it would appear that the fishery had much poorer performance than the biomass adjusted measure suggests.

5.2. Results for bigeye tuna trips only

As previously noted, there are two types of fishing in the Hawaii longline fishery. Although the fishing gear used for both types of fishing is the same, the resources and regulations facing the two types of fishing are different during their operations. In addition, the exogenous elements such as biomass condition between these two main species are different. The bigeye biomass value shows a decline while the swordfish stock was relatively stable (Fig. 2). To further understand the productivity of the two fishing methods, the bigeye tuna targeted fishing trips were examined separately for their productivity changes. Swordfish fishing trips were not examined independently because the fishery experienced a period of closure, and the data series are not complete during the full 2002–2012 period of this study.

Table 4 presents the aggregated output and aggregated input data for the tuna fishing trips only, while the Lowe indices derived from these data are shown in Table 5. When swordfish sectors are excluded from the analysis, the average Lowe index for tuna trips

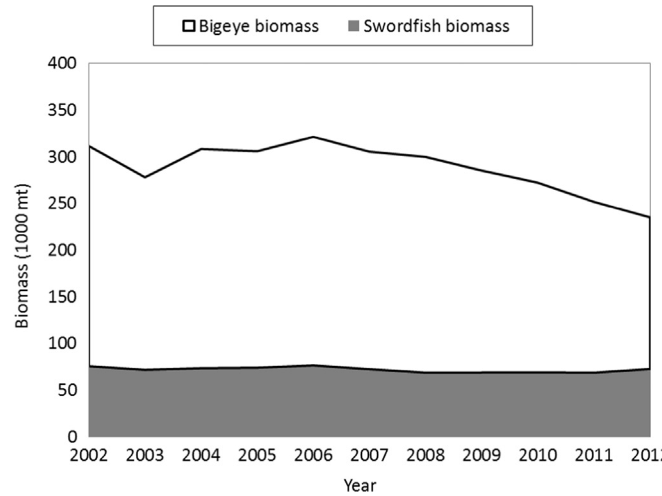

Fig. 2. The biomass trends of bigeye tuna and swordfish in the Hawaii longline fishing grounds, 2002 and 2012.

Table 4
Output and Input in the Hawaii Longline Fishery Tuna Trips.

Year	Output*	Labor*	Capital*	Total Input*	No. of Vessels
2002	55,081,416	15,368,220	1,403,270	16,771,490	97
2003	49,025,268	15,756,020	1,567,432	17,323,453	107
2004	63,224,108	17,819,942	1,801,623	19,621,565	123
2005	57,637,078	18,162,120	1,807,597	19,969,717	123
2006	53,350,084	19,061,507	1,873,628	20,935,135	127
2007	65,583,809	21,046,827	1,912,712	22,959,539	129
2008	66,538,099	21,289,675	1,903,541	23,193,216	127
2009	53,741,845	21,741,924	1,899,901	23,641,826	126
2010	60,989,982	21,196,731	1,831,262	23,027,993	121
2011	68,585,141	22,571,514	1,922,241	24,493,755	127
2012	72,699,945	24,585,977	1,922,641	26,508,618	128

* Data reported in 2010 are constant dollars using the GDP implicit price deflator.

Table 5
Output, input, and multi-factor productivity–tuna target only.

Year	Output Index	Input Index	Biomass Un-adjusted Lowe Index	Bigeye Bio-mass Index	Biomass Ad-justed Lowe Index
2002	0.96	0.84	1.14	0.98	1.12
2003	0.85	0.87	0.98	1.12	1.10
2004	1.10	0.98	1.12	0.99	1.11
2005	1.00	1.00	1.00	1.00	1.00
2006	0.93	1.05	0.88	0.95	0.84
2007	1.14	1.15	0.99	1.00	0.99
2008	1.15	1.16	0.99	1.00	0.99
2009	0.93	1.18	0.79	1.07	0.84
2010	1.06	1.15	0.92	1.14	1.05
2011	1.19	1.23	0.97	1.27	1.23
2012	1.26	1.33	0.95	1.43	1.36

during the entire period was 0.98, which was slightly higher than the average Lowe index with all trips, 0.96. In terms of the trend, the unadjusted Lowe index before the base year of 2005 is above or near 1.00, but they were all less than 1.00 after 2005. This implies that the productivity of the tuna fishery declined after 2005.

Table 6 shows the Lowe index before and after the 2005 base year for all trips, and for tuna only trips. For tuna trips, the average value of the Lowe index before and after 2005 was 1.08 and 0.93, respectively, while the figure for all trips was 1.06 and 0.91, respectively. Based on the Lowe index, depletion of the bigeye tuna

Table 6
Comparison of Lowe index before and after the 2005 base year for all trips, and tuna trips.

		Biomass index	Unadjusted Lowe Index	Adjusted Lowe Index
All trips	2002–2004	1.02	1.06	1.07
	2005	1.00	1.00	1.00
	2006–2012	1.08	0.91	0.99
Tuna trips	2002–2004	1.03	1.08	1.11
	2005	1.00	1.00	1.00
	2006–2012	1.12	0.93	1.04

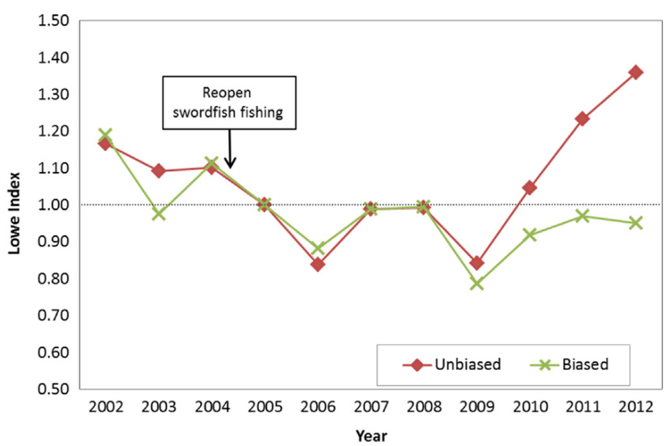

Fig. 3. Biased and unbiased Lowe index for tuna trips 2002 to 2012 (base year=2005).

resource shows a great impact on the productivity change. As Table 4 shows, the biomass of bigeye tuna increased from its low in 2003 to its peak in 2006 and then exhibited a declining trend since 2007. The biomass level in 2006 and 2007 dropped to a level similar to that of 2005. From 2009 to 2012, the bigeye tuna biomass index continuously dropped, the Lowe biomass index was 1.07, 1.14, 1.27, and 1.43, respectively for the 4 years. The 2012 index of 1.43 represents a 43% decline in adult biomass, compared to the 2005 value. When the productivity measure for the tuna-only trips is adjusted for the biomass effect, it moves in a different direction compared to unadjusted productivity. Fig. 3 illustrates the trends of the adjusted and unadjusted productivity measures for tuna fishing.

Comparison of the adjusted and unadjusted productivity measures shows the impact of biomass on the productivity of tuna fishing in the Hawaii longline fishery. For example, the bigeye tuna biomass in 2003 was relatively low, with Lowe biomass index 1.12, while it was near 1.00 for 2002 and 2004. The unadjusted index of 2003 was much lower than its neighborhood years and they were 1.14, 0.98, 1.12 for 2002, 2003, and 2004 respectively. However, after adjusting for the biomass index, the productivity measure for 2003 was up to 1.10. Apparently, the productivity of tuna fishing from 2002 to 2004 was static and high. During the period 2005–2009, both unadjusted and adjusted productivity measures went down and in 2009 they both reached time series lows of 0.79 and 0.84, respectively. Productivity was improved after 2009. The adjusted productivity shows an increase from its lowest point of 0.84, in 2009, rising continuously to 1.05, 1.23, and 1.36 in 2010, 2011 and 2012 respectively, suggesting a rapid increase of biomass-adjusted productivity of the tuna fishery in recent years. Without such an improvement in productivity, the tuna fishery would have had much poorer performance due to the depletion of the fish resources. The average adjusted (unbiased) productivity index after 2005 was 1.11, which just offset the negative impact of a biomass decline of 12% (average biomass index for the period 2006–2012). Thus, the unadjusted productivity was able to remain stable at around 1.00.

6. Discussion and conclusions

As illustrated in Fig. 3, productivity in the tuna fishery for the period 2005–2009 was relatively lower compared to the other years. The reason is unclear but it may be a result of fisheries management policy changes. The most obvious change in April 2004 was the reopening of the swordfish fishery after being closed for 4 years. While swordfish fishing was closed during 2000–2004, the majority of the swordfish vessels moved to California and these vessels then returned after the fishery was reopened [22]. The number of fishing vessels in 2003 was 107 and about 16 vessels regularly moved back to Hawaii by the end of 2004 (although the active vessels for 2003 and 2004 are the same, as shown in Table 4, but these returning vessels only operated for a limited time in Hawaii during 2004). The fishermen who used to target swordfish had to switch to tuna fishing if they remained in Hawaii. As the swordfish fishery was restricted by a series of regulations, including effort limits, which were about half of the historical level, and sea turtle interaction caps [5], swordfish fishing may have become less efficient due to both the turtle interaction caps and fishing effort caps. In addition, the returning swordfish fishermen also switched their target to tuna fishing seasonally or even completely changed to tuna fishing year-round. It was possible that a learning curve applied for the fishermen who were new to tuna fishing. On the other hand, the opposite direction of bigeye tuna price and swordfish price while bigeye price increased and swordfish price declined [5] may have provided incentive for the fishermen to focus on bigeye tuna fishing.

Overall, unadjusted productivity in the Hawaii longline fishery showed a declining trend since 2005. However, once biomass change was used to adjust the index values, the negative productivity change turned positive. The bigeye tuna biomass index in recent years went up sharply, increasing from 1.07 in 2009 to 1.43 in 2012, which implies significant declining biomass of bigeye tuna. In the same period, fishing productivity improved, as the unbiased productivity index (the adjusted Lowe index) went up steadily from 0.84 in 2009 to 1.36 in 2012. The depletion of the transboundary stocks and the adoption of turtle caps resulted in decreased productivity because fishermen had lower output with the same input or had to go further to fish resulting in higher input use.

During the study time period, especially after 2010, analytical results show that tuna fishing became more productive in term of endogenous productivity. Such an improvement of endogenous productivity has kept the fishery stable in terms of output to input ratio. Without such an improvement in productivity, the tuna fishery would have had much poorer performance due to the depletion of the shared fish resources. In addition, tuna fishing seems to be more efficient compared to swordfish fishing. The productivity measure when swordfish fishing activities were included was lower compared to estimated productivity for bigeye tuna-only fishing activities. Regulations may have impacted the productivity of the fishery. When the swordfish fishery was reopened after it was closed from 2002 to 2004, the fishery may have become less productive due to the policy restrictions which forced vessels to leave the fishery, and then possibly re-entered on a new learning curve. The "learning by doing" component of productivity change after a fishery re-opens is a topic for further research.

References

[1] J. Walden, J. Agar, R. Felthoven, A. Harley, S. Kasperski, J. Lee, T. Lee, A. Mamula, J. Stephen, A. Strelcheck, E. Thunberg, Productivity Change in U.S. Catch Share Fisheries, NOAA Technical Memorandum NMFS-F/SPO (2014) 146.

[2] PIFSC (Pacific Islands Fisheries Science Center). Hawaii longline fishery logbook statistics – non-confidential summary Tables (2002-2012). 〈http://www.pifsc.noaa.gov/fmb/reports/hlreports/2012.pdf〉. [Accessed April 21, 2015].

[3] WCPFC (Western and Central Pacific Fisheries Commission). 2013. Conservation and Management Measure For Bigeye, Yellowfin and Skipjack Tuna in The Western and Central Pacific Ocean, Conservation and Management Measure 2013-011. Commission Tenth regular Session, Cairns, Australia, 2-6 December 2013.

[4] FAO (Fisheries and Aquaculture Information and Statistics Service). On the Internet at 〈http://www.fao.org/fishery/statistics/global-capture-production/query/en〉[Accessed April 21, 2015].

[5] M. Pan, Economic characteristics and management challenges of the hawaii pelagic longline fisheries: will a catch share program help? Marine Policy 44 (2014) (2013) 18–26.

[6] WCPFC (Western and Central Pacific Fisheries Commission). 2014. TUNA FISHERY YEARBOOK 2013. Oceanic Fisheries Programme, Secretariat of the Pacific Community, Noumea, New Caledonia Pohnpei, Federated States of Micronesia.

[7] H.L. Chan, M. Pan, Spillover effects of environmental regulation for sea turtle protection: the case of the Hawaii shallow-set longline fishery, U.S. Dept. Commer., NOAA Tech. Memo. (2012) 38 , NOAA-TM-NMFS-PIFSC-30.

[8] Western Pacific Regional Fishery Management Council. 2014 Pelagic Fisheries of the western Pacific Region 2012 Annual Report. The Pelagics Plan Team and Council Staff, Western Pacific Regional Fishery Management Council. Honolulu, Hawaii.

[9] MNMP (Marine National Monument Papahānaumokuākea). 〈http://www.papahanaumokuakea.gov/about/faq.html〉[Accessed May 1, 2015].

[10] PIRO (Pacific Islands Regional Office) False Killer Whale Take Reduction Team and Plan Frequently Asked Questions. 〈http://www.fpir.noaa.gov/Library/PRD/FKW%20TRT/FKW-TRP-FAQ-11.12.pdf〉. [Accessed May 1, 2015].

11] N.C. Pradhan, K.R. Sharma, P. Leung, Analyzing technical and economic interrelationships in Hawaii's longline fishery, Marine Resource Economics 18 (2003) 167–194.

[12] K.R. Sharma, P.S. Leung, Technical efficiency of the longline fishery in Hawaii: an application of a stochastic production frontier, Marine Resource Economics 13 (1999) 259–274.

[13] M. Barnes, K. Kalberg, M. Pan, P.S. Leung, When is brokerage negatively associated with economic benefits? Ethnic diversity, competition, and common-pool resources, Social Network (2015) (under review).

[14] D. Squires, Index Numbers and Productivity Measurement in Multispecies Fisheries: An Application to the Pacific Coast Trawl Fleet, NOAA Technical Report NMFS (1988) 67 , National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

[15] C.J. O'Donnell, Nonparametric Estimates of the Components of Productivity and Profitability Change in U.S. Agriculture, American Journal of Agricultural Economics 94 (4) (2012) 873–890.

[16] D.W. Caves, L.R. Christensen, W.E. Diewert, "The economic theory of index numbers and the measurement of input, output, and productivity.", Econometrica no. 50 (6) (1982) 1393–1414.

[17] J.B. Walden, J.E. Kirkley, R. fare, P. Logan, Productivity change under an individual transferable quota management system, American Journal of Agricultural Economics 94 (4) (2012) 913–928.

[18] N.C. Pradhan, P.S. Leung, Modeling entry, stay, and exit decisions of the longline fishers in Hawaii, Marine Policy 28 (2004) (2004) 311–324.

[19] D. Squires, "Productivity measurement in common property resource industries: an application to the Pacific coast trawl fishery.", Rand Journal of Economics 23 (2) (1992) 221–236.

[20] S. Harley, N. Davies, J. Hampton, S. McKechnie, Stock assessment of bigeye tuna in the western and central Pacific Ocean Rev 1 (25 July 2014), Western and Central Pacific Fisheries Commission (2014), WCPFC-SC10-2014/SA-WP-01.

[21] Chang, Y.J., Yau, A.J., and Brodziak, J. (working paper in press). Stock assessment of Western and Central North Pacific Ocean swordfish (Xiphias gladius) through 2012. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396. Pacific Islands Fish. Sci. Cent. Admin. Rep. H-15-XX,.

[22] S.D. Alen, A. Gough, Monitoring environmental justice impact: Vietnamese-American longline fishermen adapt to the Hawaii swordfish fishery closure, Human Organization 65 (3) (2006) 319–328.