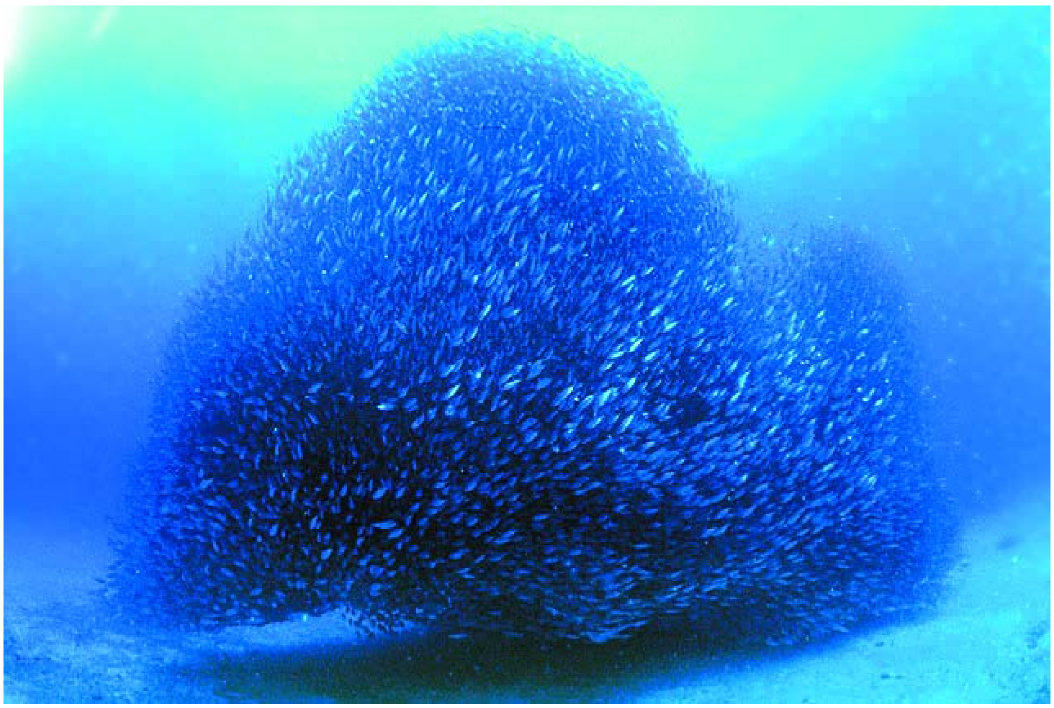
Characterization of the akule fishery in the island of O'ahu, Hawai'i: Potential utility of aerial spotter data to enhance fishery information



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Western Pacific Regional Fishery Management Council
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Characterization of the akule fishery in the island of Oahu, Hawaii: potential utility of aerial spotter data to enhance fishery information

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A technical report submitted to the Western Pacific Regional Fishery Management Council

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Historical characterization of the akule fishery in Oahu

ABSTRACT

The big eye scad (*Selar crumenopthalmus,* locally known as akule) is an important food source for many Hawaiians and represents one of the most productive near-shore fisheries in Hawai'i. These fish occupy an intermediate trophic link between the coastal environment in which they feed and the pelagic migrations of their predators. This study first reviews the akule fishery throughout Hawai'i and then focuses on the island of O'ahu. The vast majority of akule harvested around O'ahu are caught along the southern and western coastlines. The catch per unit effort (CPUE) for this species has remained relatively consistent over the previous 20 years. Akule are most often fished using surround nets deployed from a fishing vessel. The boats frequently work in tandem with spotter planes to efficiently target appropriate schools. These spotter planes may provide the means for a fishery-independent apparent abundance estimation based on direct observation, which may prove more sensitive to population trends than traditional CPUE based estimates.

Background Information

Biology/ecology

The bigeye scad, *Selar crumenophthalmus*, is a member of the Family Carangidae. This species has relatively large eyes, a small mouth, a fusiform body shape, and weak scutes (Figure 1). They have a circumtropical distribution throughout the Atlantic, Indian, and Pacific Oceans, including the warm coastal waters of all the Hawaiian Islands. According to fishermen testimony and tagging studies, the adult fish rarely venture offshore (Kawamoto 1973). Despite utilizing a near-shore habitat, bigeye scads are still considered coastal pelagic species because they do not rely on a substrate. In Hawaiian waters, bigeye scads are commonly referred to as "akule" when their total length exceeds 22 cm (8.7 in); shorter individuals are called "hahalalū" (Iwai et al. 1996).

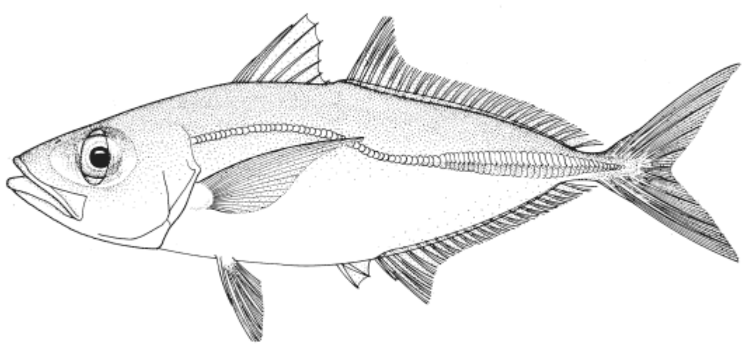

Figure 1. An adult bigeye scad (akule) (Online Source: Food and Agriculture Organization).

Akule are fast growing species reaching sexual maturity at a standard length of about 20 cm (7.9 in; Clark and Privitera 1995). Weng and Sibert (2000) estimate this to occur in seven months based on the length fit to a von-Bertalanffy growth curve produced from tag-recapture experiments by Kawamoto (1973). Mature individuals are found to be sexually dichromatic during the spawning season with the soft portion of the anal fin appearing dark black in males and white in females (Clark and Privitera 1995). Fertilization occurs externally with free floating eggs (Kawamoto 1973). Monthly examinations into the reproductive organs of the akule revealed the gonads to be predominantly mature or spent during the months of April through November. This eight-month period is thus considered the main spawning period for akule (Kawamoto 1973). Hahalalū first appear in large schools in July and are continually recruited through December, suggesting a four month growing phase during the ichthyoplanktonic life stage (Kawamoto 1973).

Bigeye scads raised in captivity also spawned in accordance to these natural patterns from April through November during their first year. After this initial year, the captive broodstock spawned repeatedly throughout the following year (Iwai et al. 1996). It is unclear if wild akule are capable of such repeated spawning after the first year due to an estimated annual mortality rate of 99.3% (Kawamoto 1973) combined with a maximum life span of only two and a half years (Ralston and Williams 1988).

Bigeye scads are thought to feed mainly by night. Stomach content analysis revealed empty stomachs of fish sampled during the day, while those sampled at night generally contained food (Roux and Conand 2000). These results suggest unusual feeding patterns for akule given many epipelagic fish are unable to locate prey and feed at night. The relatively large eyes of the akule may account for their ability to locate and feed on macroplankton in limited light.

Small fish (anchovies, holocentrids, etc.), copepods, crab megalops, stomatopods, shrimps, and other free swimming crustaceans form the basis of the akule's coastal diet (Kawamoto 1973; Roux and Conand 2000). Akule are preyed upon by larger pelagic carangids, billfishes, and tunas that frequent the near-shore waters (Kawamoto 1973). Thus, akule occupy an intermediate trophic level connecting the near-shore environment where they feed to the offshore environment of their predators (Weng and Sibert 2000).

Commercial Fishery

Fishing Methods

Two main commercial fisheries for bigeye scads currently exist in Hawai'i, each capitalizing on distinct behaviors. First, the hand line fishing method was introduced to the Hawaiian Islands by Japanese immigrants before World War I (Kawamoto 1973). This method involves fishing from a vessel at night while utilizing a light to attract plankton, anchovies, and other food sources. Subsequently, the akule attracted to the area are hooked by the fishermen between the surface and about 10 m (33 ft) within waters generally less than 100 m (330 ft) in depth (Powel 1968). The hand lines are typically constructed of lightweight materials with three to five baited hooks or lures. Single boats with one to two fishermen typically catch 18-23 kg (40-50 pounds) of akule per night using this method (Kazama 1977).

Surround netting operations comprise the second commercial fishing strategy for Hawaiian bigeye scad. This strategy capitalizes on the compact schooling tendency of this species during the morning hours and was outlined in detail by Kazama (1977). Historically, early Hawaiians trapped akule in beach seine nets restricted to shallow shoreline waters within bays and inlets (Kawamoto 1973). Fishermen were directed to the schools of fish by spotters using hand signals upon higher grounds or up in a tree (Kazama 1977). Technological improvements such as airplane fish spotters, net design, the use of SCUBA divers, and larger fishing vessels drastically improved the efficiency of the surround net fishery (Kawamoto 1973; Kazama 1977).

Bag nets and gill nets comprise the two types of net utilized by the modern Hawaiian surround net fishery. The bag net is a combination of bag and seine net consisting of 3.8 cm (1.5 in) nylon mesh webbing. The seine net consists of a large panel with floats on the top line and a weighted bottom line. It is formed by lacing 100 m (330 ft) long sections together until the desired length is achieved. These nets vary in depth from 12 to 26 m (39 to 85 ft) depending on water depth. The seine net is first deployed by the vessel as it circles the school of akule. Divers then attach the bag to the bottom of this vertical net wall. Next, the fish are funneled into the bag by restricting the circular seine net. Once all the fish have entered the bottom bag, the fish are lifted onto the vessel. This method of fishing routinely catches the majority of fish in the school (Kazama 1977).

The gill nets are constructed with monofilament line to form a wall of 6.3 cm (2.5 in) webbing. These nets also have floats attached to the top of the net panels and weights on the bottom. Each section of net is typically 42 to 100 m (138 to 330 ft) in length and can be laced together for the desired length. Gill nets are set by vessels encircling the fish. Rather than cinching the net tight and herding the fish into an attached bag, divers enter the water and scare the akule into the surrounding gill net causing entanglement. A smaller percent of the school is typically caught using the gill nets because of the increased possibility for escape (Kazama 1977).

Commercial Catch

In the last 65 years, the annual commercial landings of bigeye scads within Hawaiian waters have varied greatly from a maximum of 1,117,018 pounds in 1998 to a minimum of 147,998 pounds in 1963 (Figure 2). The landings of akule increased from the late 1960s to the early 1980s and then again from the early 1990s to 2000. The most recent data (Hawaii Division of Aquatic Resources published through WPacFIN 2014) for annual landings suggest a relatively low average annual yield of 226,192 pounds from 2004 to 2013, which is comparable to the decline observed in the 1950s.

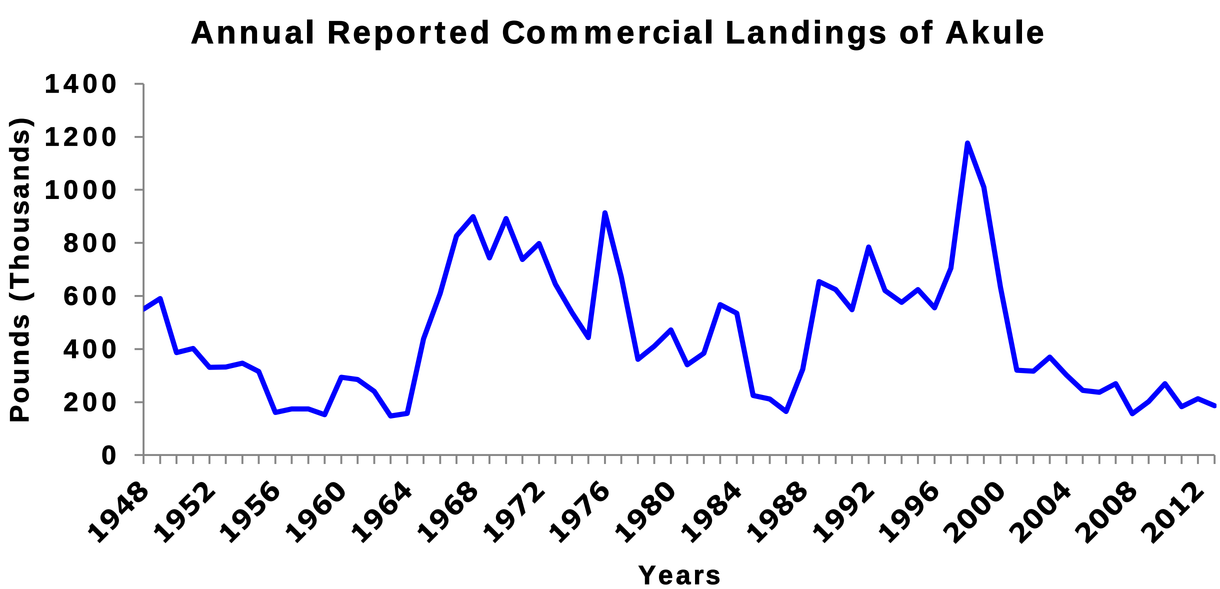

Figure 2. The annual reported commercial landings for akule for the state of Hawai'i spanning from 1948 to 2013.

Specific causes for such large variance in long-term landings for the akule in Hawaiian waters are currently lacking. Kawamoto (1973) suggested that the market for commercially caught akule is highly localized, focused by O'ahu's demand for fresh fish. Fluctuations in demand may be the primary driver for fishing effort and subsequent catch. A previous fisheries analysis revealed that yearly catch and effort have been strongly correlated for akule (Weng and Sibert 2000). Additionally, this study used both vector-*k* and scalar-*k* models (Schaefer 1954) in determining that akule has undergone light to moderate exploitation respectively. Although this study lacks data past 1995, it supports the argument that yearly catch fluctuations are more dependent upon social pressures dictating effort rather than population abundance.

Population availability, which is largely affected by high recruitment variability, also drives potential fluctuations in catch. Akule share many life history characteristics with other coastal pelagic fish such as those within the Family Clupeidae. Broadcast spawning, high natural mortality rates, fast population turnover, and relatively short life-spans are all similarities that can contribute to recruitment variability. Populations of both northern anchovy, *Engraulis mordax*, and Pacific sardine, *Sardinops sagax*, showed the most sensitivity to natural variation in parameters of larval stages (Butler et al. 1993). Early development of bigeye scads may also be the most impactful period affecting natural population availability.

Regulations

There are currently two regulations restricting the take of akule. The first was established in 1929 and states that the mesh size of nets used for fishing must be at least 38 mm (1.5 in). In 1968, the second regulation was enacted in response to a drop in catch between 1951 and 1965, which prohibited the netting of hahalalū under the total length of 21.6 cm (8.5 in) between July and October. This regulation was designed to help protect young hahalalū during their peak recruitment period.

Physical Parameters and Stock Size

Physical parameters within the environment have the potential to drive akule population dynamics. Weng and Sibert (2000) demonstrated a positive correlation between the predicted carrying capacity derived from the Shaefer model (Schaefer 1954) and terrestrial precipitation on Mauna Loa. The akule carrying capacity time series was lagged two years after precipitation events. For example, the 1990 carrying capacity value was compared to the 1988 precipitation value. The two-year lag time suggests variations in precipitation mostly affect recruitment success or early development of akule within Hawaiian waters. This study suggests the observed pulse in akule abundance following high rainfall events two years prior may be caused by the increased runoff fertilizing the coastal ocean.

Aerial Surveys for Fishery Management

The use of aerial spotting planes has provided a means for direct observations of many marine species found on or near the ocean surface. This method of surveillance has been largely utilized in scientific surveys for estimating population sizes and distributions of large marine animals spanning many taxonomic groups such as turtles (Marsh and Saalfeld 1989; Roos et al. 2005; Witt et al. 2009; Jean et al. 2010), dolphins (Slooten et al. 2004), dugongs (Marsh and Sinclair 1989; Pollock et al. 2006), sharks (Cliff et al. 2007; Rowat et al. 2009; Kessel et al. 2013), and tunas (Hoggard 1995; Polacheck et al. 1997; Lutcavage and Newlands 1999; Fromentin et al. 2003; Baron 2010; Bonhommeau et al. 2010).

Spotter planes are also routinely used in commercial fishing endeavors to maximize efficiency in locating target schools. This offers a convenient means for providing relatively inexpensive, direct observational data for these near-surface schooling fish. These data can then be used for the development of fishery-independent estimates of apparent abundance. Apparent abundance is defined as "abundance as affected by availability, or the absolute number of fish accessible to a fishery" (Marr 1951). This approach deviates from scientifically designed surveys by using data acquired through normal fishing activity. Interpreting such data may be more difficult as its collection is opportunistic rather than specifically designed to the study.

The development of fishery-independent apparent abundance estimates for akule would provide comparable findings to the standard estimates derived from catch per unit effort (CPUE). This would generate an additional tool to help decipher possible biases and limitations within the two distinct methods. It has been suggested that an integrated approach for stock assessment combining data from fishery-independent and fishery-dependent sources will best meet future management needs (Barnes et al. 1992). Such an approach will alleviate the inherent weaknesses of any one method and provide a more robust estimate of abundance.

Aerial spotter abundance estimates offer advantages over the CPUE strategy. Data attained from commercial CPUE are subject to saturation because of hold capacity, trip limits for catch, market demand, or processing capacity (Lo et al. 1992). In contrast, fish spotters are capable of reporting the entirety of all observed species. Also, aerial spotter efficiency is less likely to be influenced by technological advances through time as schools must still be located visually while flying at low speed and low altitude. Commercial fishing efficiency, however, has improved greatly due to technological improvements to nets and acoustic fish finding equipment. It has been demonstrated that CPUE can be maintained even as actual fish abundance decreases (Harley et al. 2001).

Aerial survey biomass estimates also introduce unique problems when used to estimate apparent abundance. Possible sources of error include environmental conditions hindering detectability of the fish (e.g. cloud cover, glare, water turbidity, wind, wave height, etc.), animals too deep to spot, and the skill of the pilot spotting schools and estimating size. Additional variation may be introduced when multiple pilots are used (Marsh and Sinclair 1989; Lo et al. 1992; Rowat et al. 2009).

Many aerial surveys directed towards fishery abundance testing reported in the literature use line-transects to search for target species. These species are predominantly highly mobile tuna with extremely wide distributions (Hoggard 1995; Fromentin et al. 2003; Baron 2010; Bonhommeau et al. 2010). Tuna surveys have difficulty maximizing sightings based on these extensive distributions. Furthermore, tuna are large predatory fish occupying a higher trophic level than akule. Akule offer a more consistent study group with predictable coastal schooling behavior during the early morning hours around the island of O'ahu. Using the transect methodology for studying akule would not be justified based on such dissimilarities between species and spatial parameters.

Akule aerial surveys should be more closely modeled after studies on northern anchovies and Pacific sardines in Californian waters (Squire 1972; Barnes et al. 1992; Lo et al. 1992). These species share a more similar ecological niche and also school in large numbers near the ocean's surface. Squire (1972) assigned aerial observations of biomass to zones that outlined important geographical areas in which fish were commonly encountered. An index of apparent abundance was then determined as tons sighted per zonal area. Similar grids have been assigned to the waters surrounding O'ahu. These serve as the area basis for this preliminary study on the viability of utilizing aerial surveys to generate an index of apparent abundance for bigeye scad.

Historical Catch

Data Acquisition

Spanning 65 years, 1949 to 2014, data for the historical catch of akule around O'ahu were acquired through the Hawaiian Division of Aquatic Resources (DAR). The utilized datasets include fiscal year, method of fishing, quadrat, number of licensees, total pounds landed, and trip count. The different fishing methods include inshore hand line, gill net, purse seine net, seine net, and miscellaneous net. The different quadrats represent the shoreline from which the akule were captured: North, East, South, or West. The quadrats encompass numbered area grids surrounding the island (Figure 3). The number of licensees shows how many commercial vessels reported to catch and sold akule. The total pounds landed provide the annual catch for the commercial fleet of O'ahu. The trip count provides the total number of fishing trips completed by the commercial fleet. Total catch and total trip count allow for the calculation of catch per unit effort (CPUE) in the form of catch per fishing trip.

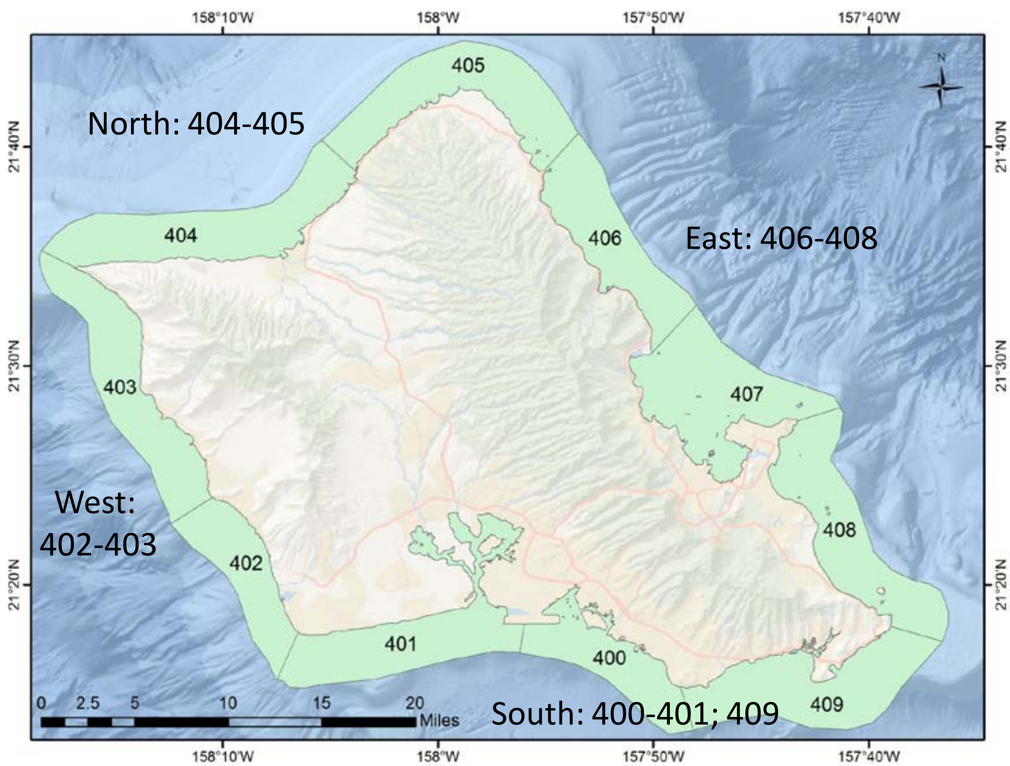

Figure 3. Map of O'ahu displaying the numbered fishing grid areas and the quadrats to which they belong.

<u>**Data Summary**</u>

In general, the time series illustrates catch and total commercial fishing trips varied greatly over the 65 years and changed in parallel, except during the late 1960s to early 1970s (Figure 4). During this period, the catch surpassed the trip count which is captured in the CPUE time series (Figure 5). The CPUE quickly increased fivefold in the late 1960s, then decreased back down around the initial value through 1988, and finally stabilized in between these values where it remained relatively consistent over the last 20 years. The number of boats licensed to commercially fish akule varied greatly between a high of 181 in 1983 and a low of 28 in 1959 (Figure 6).

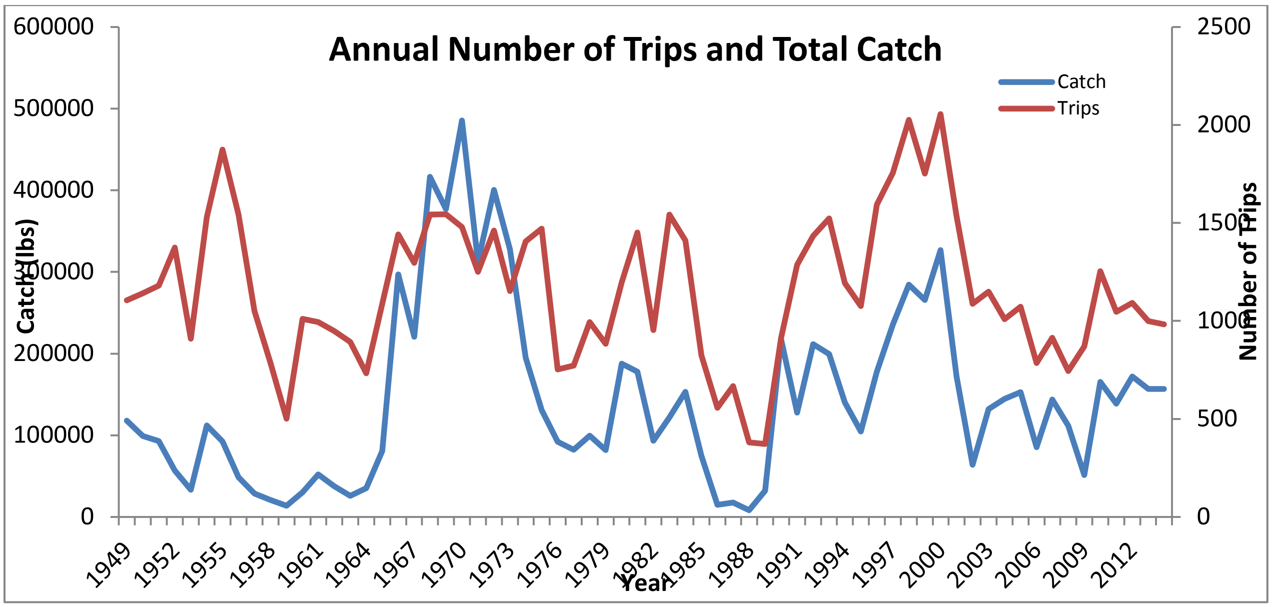

Figure 4. The reported annual commercial catch (lbs) of akule with total number of commercial fishing trips from 1949 to 2014 around the island of O'ahu.

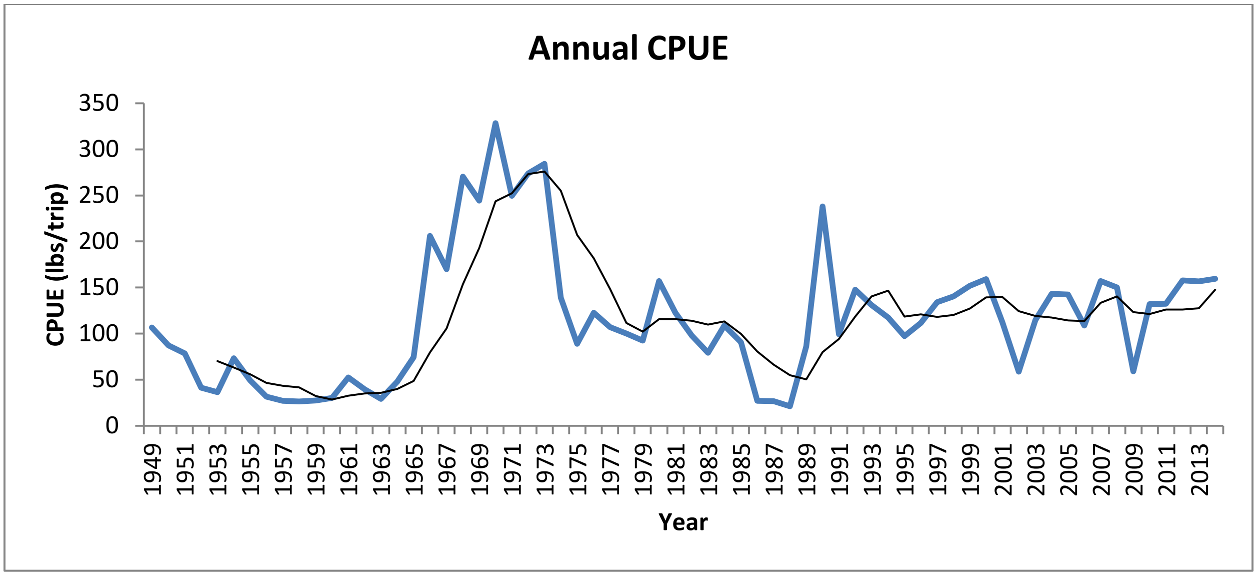

Figure 5. The reported annual commercial CPUE (lbs/trips) from 1949 to 2014 around the island of O'ahu. The blue line shows actual values while the black line has been smoothed by five year averages.

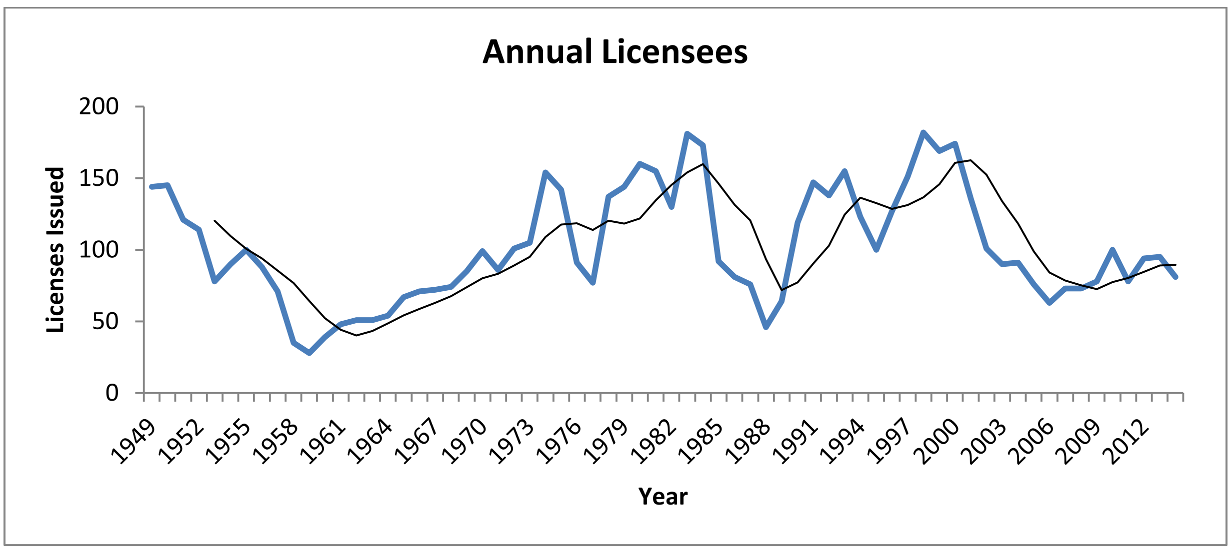

Figure 6. The annual commercial licenses issued for take of akule from 1949 to 2014 around the island of O'ahu. The blue line shows actual values while the black line has been smoothed by five year averages.

The fished quadrat location records captured in the data allowed for a spatial analysis of akule caught around O'ahu. Annual catch averages clearly show the vast majority of akule were caught along the southern and western coastlines (Figure 7). There is no significant catch difference between these two coastlines. These two areas accounted for three quarters of the mean annual catch.

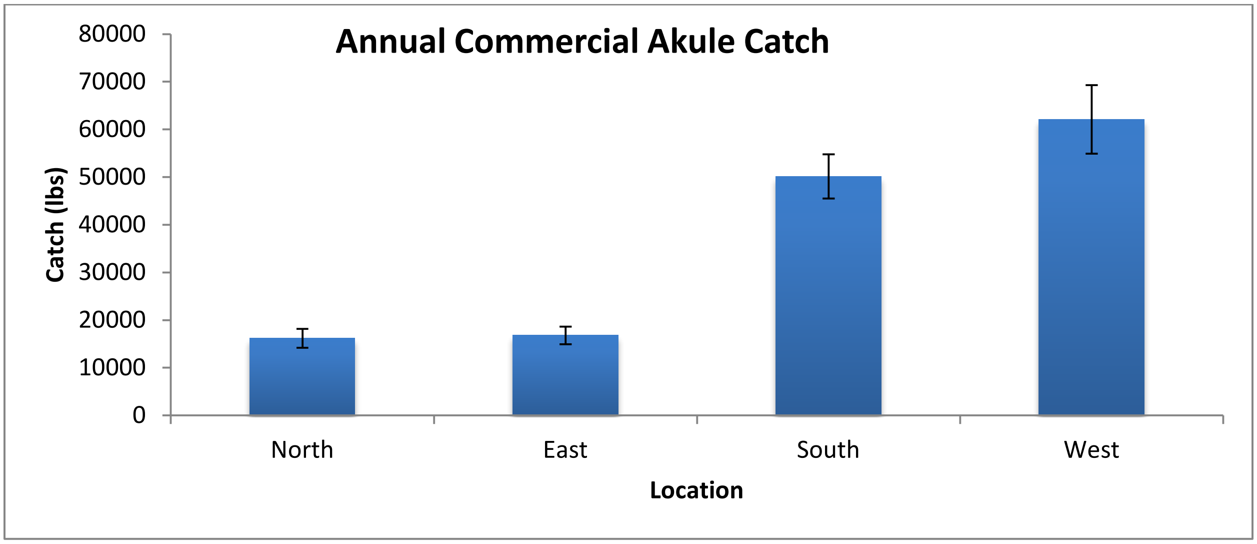

Figure 7. Mean annual commercial catch (lbs/year) of akule from 1949-2014 broken up by quadrat for the island of O'ahu. Error bars represent one standard error in either direction.

The spatial catch around O'ahu was further broken down by the fishing method employed (Figure 8). The primary method used to harvest akule was the utilization of surround nets. The West quadrat was responsible for the greatest amount of akule caught using these nets. Inshore hand lines accounted for the majority of catch within the South and nearly half of the catch in the North. These areas also had the lowest CPUE (Figure 9). The East shoreline had the highest percentage of catch from surround nets. Although this quadrat had lower annual akule catch, it had the highest CPUE.

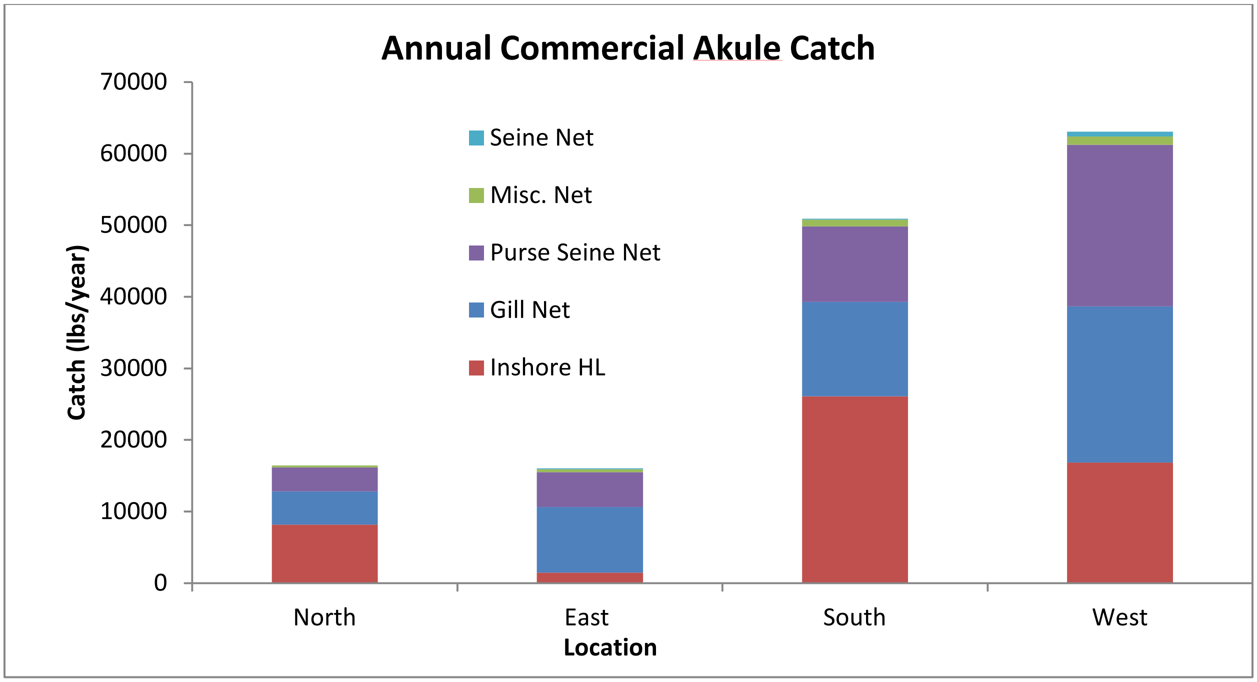

Figure 8. Mean annual commercial catch (lbs/year) of akule from 1949-2014 by quadrat for the island of O'ahu. Different colors represent the different gear type used.

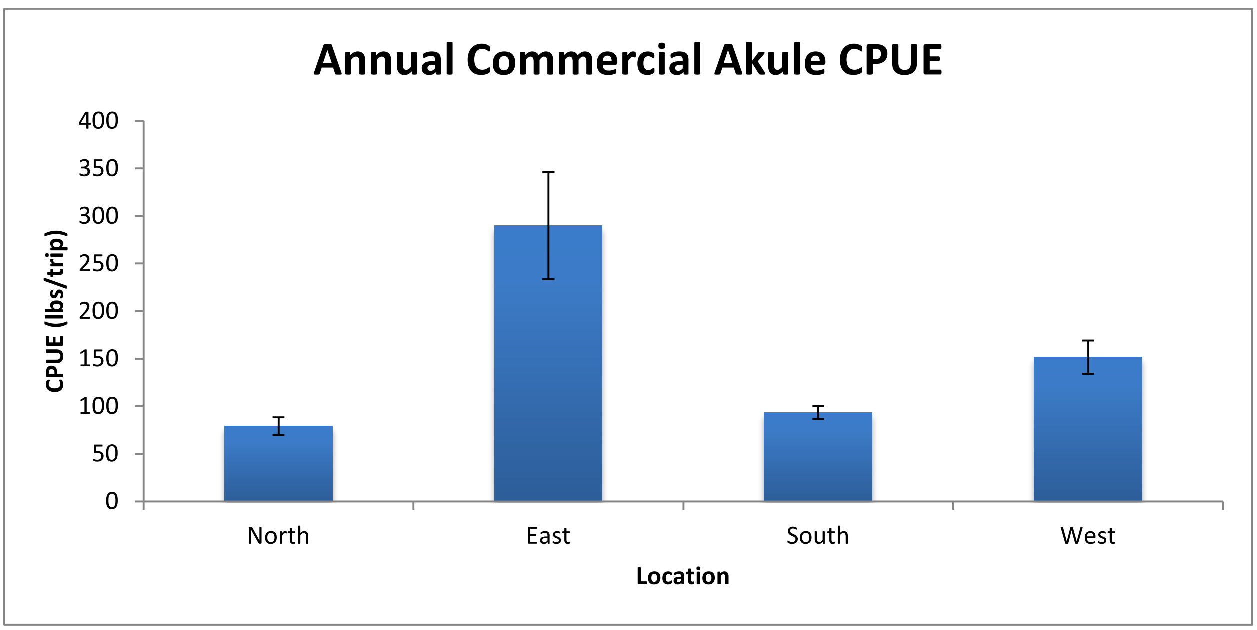

Figure 9. Mean annual commercial CPUE (lbs/trip·year) of akule from 1949-2014 broken up by quadrat for the island of O'ahu. Error bars represent one standard error in either direction.

Discussion

It is currently unclear if the greater catch observed along the southern and western coastline is related to lower akule abundance in other areas. This discrepancy may be due to fishermen preference rather than absence of fish (Pers. Comm. Kaipo Miller, commercial fisherman June 1, 2015). The spotting planes used by the fishing fleet to target schooling akule typically take off on the southwestern side of the island, requiring less effort to spot schools in this area. Additionally, ocean conditions are typically calmer on that side of the island where the grounds are more protected from the trade winds. Such conditions allow for safer and easier fishing, concentrating effort in these areas.

The surround net fishing methods are far more efficient than the inshore hand line method based on a trip basis. Intuitively, this makes sense as the hand line operation is much smaller; typically one boat with two fishermen catches about 18-23 kg (40-50 pounds) each night (Kazama 1977). This explains why the North and South, areas with highest hand line catch percentage, have the lowest CPUE based on trips. Conversely, surround net operations are able to capture a much larger amount of akule per trip. This is evident when observing the East, which had the highest CPUE because surround nets accounted for the highest percentage of catch. Using CPUE to estimate apparent abundance of akule without accounting for the various methods of commercial harvesting may contain severe bias. The current method of reporting catch per trip does not allow one to account for this bias unless hand line catch is analyzed separately.

The reporting nomenclature currently utilized by DAR for the various types of fishing for akule may be flawed. Fishermen do not use purse seine nets to catch akule. As previously described, the two types of surround nets employed by fishing vessels are the gill net and bag net (Pers. Comm. Kaipo Miller, commercial fisherman June 1, 2015). Because of the large volume of catch attributed to the purse seine net in the DAR database, it is likely bag nets were mislabeled as such. Additionally, the "seine net" label might be replaced with "beach seine net" to minimize confusion on which nets are utilized on land or by sea.

Estimating akule abundance around Oahu using aerial spotters

ABSTRACT

Akule are frequently fished in coordination with a spotter plane to maximize efficiency in locating a target school. These planes were utilized to collect direct observational data on akule biomass around the island of O'ahu, which were used to create fishery-independent indexes of apparent abundance at varying temporal and spatial scales. By far, the largest index value was found along the western shoreline. This value was nearly four times greater than the next largest index along the southern shoreline. A positive correlation was found between the aerial biomass estimates and fishermen catch per unit effort (CPUE) from the spotted school. This shows some connection with traditional fishery-dependent CPUE based estimates of abundance. Long-term trends in each method can be compared once a longer time series using aerial spotters has been established.

Introduction

Bigeye scads represent the largest proportion of total landings among species listed in the Fishery Ecosystem Action Plan (FEP) for the Hawaiian Archipelago (WPRFMC 2009). The primary method used to commercially harvest akule utilizes surround net fishing gear. These operations are often performed in coordination with spotter planes. The planes are far more efficient in locating appropriate schools for the fishermen to target. Each morning, schools of hahalulū and akule form in the coastal areas surrounding O'ahu for protection. The spotter planes relay the location and estimated size of these schools to the fishermen aboard the vessel. The fishermen rely on the pilot's accuracy in determining the most advantageous school to pursue. A previously Council funded cooperative research project using Sustainable Fisheries Fund showed that spotter pilots can accurately estimate the size of the individual fish along with the total biomass of each spotted akule school.

As specified by the Magnuson-Stevens Fishery Conservation Reauthorization Act of 2006 (MRSA), fish species listed in FEPs are required to have reference points based on the best available science. Currently, akule reference points are calculated based on catch per unit effort (CPUE) data from harvests. A stock assessment for akule was last (and first) done by Dr. Kevin Weng and Dr. John Sibert in 2000, using historical catch and effort information from the state of Hawai'i commercial reporting database (Weng and Sibert 2000). However, CPUE can be insensitive to change in abundance, especially for pelagic schooling species (Pitcher 1995). The susceptibility of schools to harvest can remain unchanged as the number or size of the schools decline, thereby masking changes in population size.

This pilot project leveraged information from aerial spotter surveys on the number of schools, as well as fishermen's unique knowledge about akule size and school biomass to begin the development of a time series of relative abundance that is more sensitive to changes in population size than traditional CPUE time series. The Council, in partnership with the local fishermen developed this study to determine the feasibility for spotter pilots on the island of O'ahu to collect the needed information on akule school number and size.

The development of this fishery-independent approach would provide a new means for estimating apparent abundance for akule. The additional measurement can be combined with and compared to the CPUE based estimates. A more accurate understanding of population dynamics will allow greater confidence in managerial decisions. Barnes et al. (1992) suggested that integrating data from both fishery-independent and fishery-dependent methods would provide the most robust stock assessment.

Methods

Fishermen using a spotter pilot were contracted to facilitate the data collection for this project. The pilot conducted 52 aerial surveys around the island of O'ahu during the early morning and afternoon. These flights occurred during the 2014 commercial akule fishing season, beginning on the fifteenth of April and lasting until the second of September. Aerial operations occurred within the two nautical mile state waters along the shallow coastal areas. Spotted schools were assigned to grids which compose each shoreline of O'ahu (Figure 3). Each grid did not receive equal searching effort as data was collected in accordance with normal fishing practices. The plane ran at the slowest possible speed deemed safe at altitudes ranging from 500 to 1200 ft to maximize school sightings.

A single pilot was used throughout the duration of the study to limit possible variation introduced by differing skill levels between multiple spotter pilots (Lo et al. 1992). During each flight, the pilot took pictures of the spotted schools with a smart phone capable of time and GPS stamping. The pilot then labeled each picture with his estimated biomass for the entire school. An onboard GPS unit was also used to track each flight path, which allowed searching times within each grid area to be calculated.

Measures were taken to ensure consistency of animal detectability using aerial observations, which may otherwise have been negatively affected by environmental conditions such as cloud cover, glare, water turbidity, wind, wave height, etc. (Marsh and Sinclair 1989; Lo et al. 1992; Rowat et al. 2009). Aerial surveys were only conducted on days without rain. Wave height and wind speed were always low enough to ensure safe fishing and greater spotting ability. The consistently clear water surrounding O'ahu enhanced the pilot's power to spot schools of akule. Glare was the leading environmental factor in reducing detectability (Pers. Comm. Kaipo Miller, commercial fisherman June 1, 2015).

The fishermen then targeted a school in accordance with the spotter pilot. Surround gill nets were used to harvest akule from this school whose biomass had been previously estimated by the pilot.

The fishermen recorded their catch (lbs) and other pertinent information from each fishing trip. A total of 26 fishing trips were conducted.

Analysis

Two correlations were attempted to determine possible relationships between datasets. The association between catch (lbs) and effort (hrs) of the fishermen was determined. These data required no transformations or assumptions. A separate correlation was done between the pilot's biomass estimates (lbs) and the resulting CPUE (lbs/trip) by the fishermen aboard the vessel. The estimated school size data had associated assumptions. Two points were missing estimates so these trips were thrown away. Two other trips were discarded as outliers greater than two standard deviations from the mean. Values for estimated biomass were averaged if a range of values was given as an estimate.

Indexes of apparent abundance were created based on the aerial spotter pilot estimates for various spatial (reporting grid, quadrat, island wide) and temporal (monthly, seasonal periods, total fishing season) scales based on the following formula for total biomass per flight searching time:

Index of Relative Abundance $= \sum_{i=1}^{N_{t,r}} B_{i,t,r} \,/\, \sum_{i=1}^{N_{t,r}} T_{i,t,r}$

Where: $B_{i,t,r}$ = biomass of school *i* in time period *t* and region *r*

$T_{i,t,r}$ = time (hrs) spent searching for schools during flight *i* in time period *t* and region *r*

$N_{r,t}$ = total number of flights in time period *t* and region *r*

The flight paths from the GPS unit were downloaded and search times were calculated as total time spent over each fishing grid. The grids were expanded 750 m inland to include a greater search area accounting for the detectability of schools at altitude (Rowat et al. 2009). Gaps in the time series within a specific grid greater than five minutes were excluded from calculated search times. Any gap less than or equal to five minutes was assumed relevant and contributed to the search time.

Many flights could not be included in the calculation of indexes of relative abundance due to user error. Of the 52 total flights, 31 were used in the analysis to ensure accuracy. No flights were utilized from the months of April and September. This left only May representing the pre-season and zero representative months for the post-season.

Results

During the 2014 fishing season, the pilot spotted a total of 115 schools of akule ranging in size from 2000 lbs to 80,000 lbs with an average size of 10,000 lbs. The fishing season was further broken down into pre-, peak, and post-season. During the pre-season (March - May), 12 flights resulted in a total of 36 spotted schools averaging 11,900 lbs. During the peak season (June - August), 38 flights resulted in a total of 76 spotted schools averaging 9,100 lbs. During the post-season (September – November), two flights resulted in a total of three spotted schools averaging 9,300 lbs. Thus, average estimated school size dropped over 20% following the pre-season on this temporal scale.

The fishermen harvested a fraction of the estimated biomass with a single trip maximum of 3,000 lbs. Their most efficient trip captured 37% of the fish observed by the spotter pilot. However, this trip represented the only outlier greater than two standard deviations from the norm within the catch to biomass ratios (Figure 10). The average percent harvested from the targeted school was 14%. There were also five instances where less than 1% of the projected biomass was captured by the fishermen. The schooling fish on these trips were noted to have spooked before a net could be fully deployed or the school consisted of hahalalū.

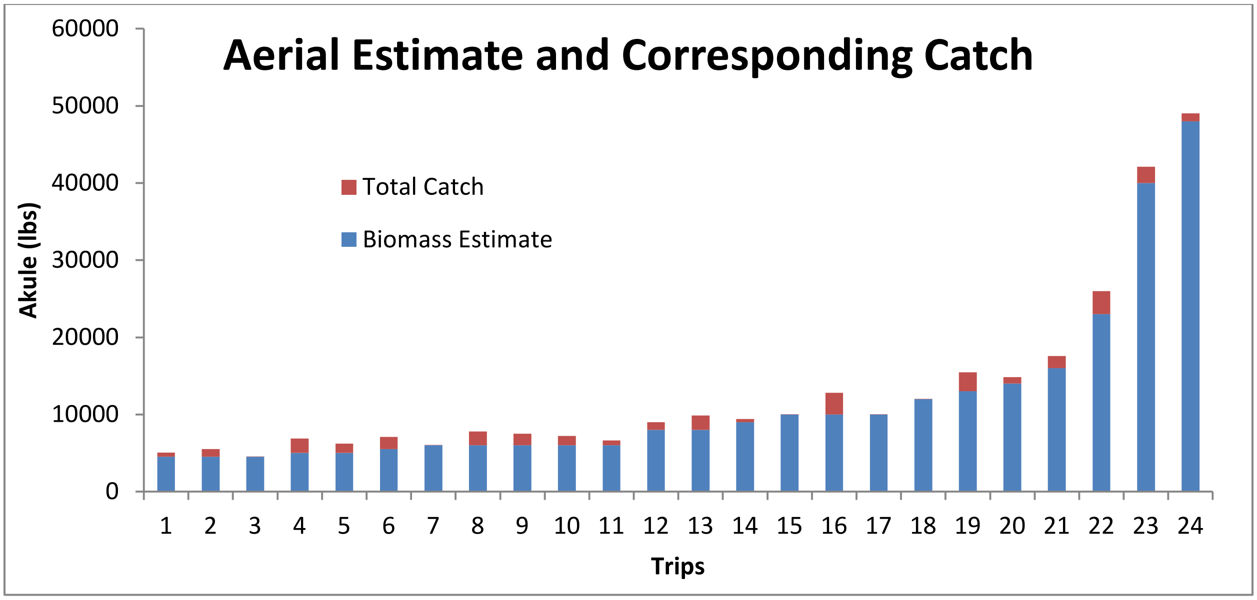

Figure 10. Estimated biomass (lbs) from the spotter pilot for each targeted school of akule (blue) and the resulting catch (lbs) by the fishermen (red).

Three pictures capturing the spotted schools of akule lacked GPS data, leaving a total of 112 schools that were plotted in GIS (Figure 11). The gridlines are shown in the figure to illustrate the increased area incorporating greater detectability of the pilot at altitude. A few geotagged photos are further inland than these cutoffs, which is attributed to cell phone GPS accuracy limitations. These points were assigned to the closest grid. The vast majority of schools were located in grids 401, 402, and 403 along the southern and western coastline. These three grids accounted for 84% of the total schools spotted throughout the season; grids 405, 406, and 407 contained a total of one spotted school between them.

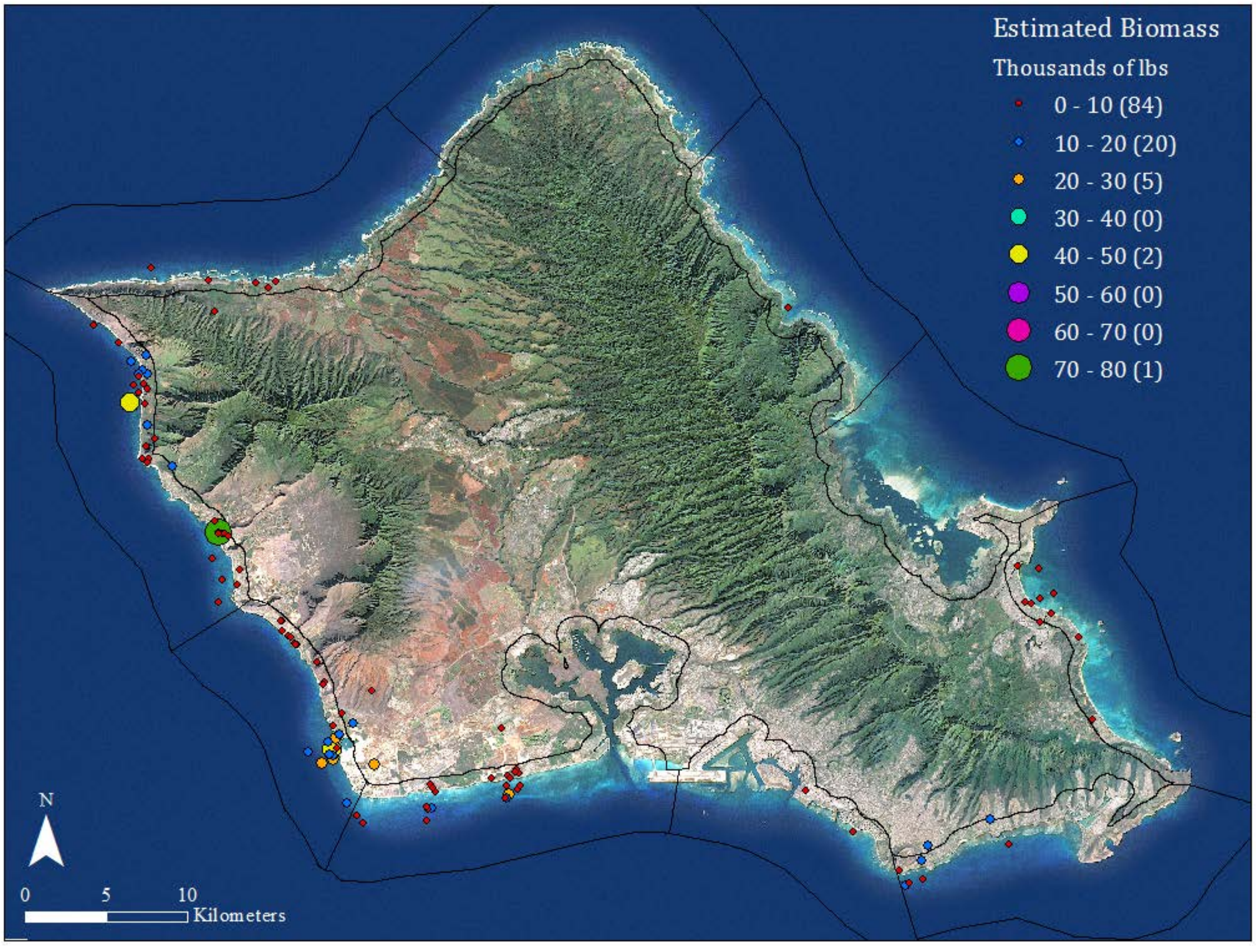

Figure 11. Aerial estimated biomass represented by varying size/color of circles demonstrating the spatial position of akule schools surrounding O'ahu. The black grids illustrate the DAR fishing grids used

The indexes of relative abundance were greatly skewed on the lowest spatial and temporal scales because of the limited usable sample size and are not provided in this report. These values stabilized using larger scales and are shown in Table 1. The highest index value was observed during the peak season along the western shoreline. Overall, the peak season (June-Aug) yielded far higher index values than during pre-season (May). The index of the southern shoreline suffered greatly due to the high search time and zero spotted schools in grid 400. Despite this hindrance, the South quadrat still exceeded the North and East quadrats. Additionally, the South and West received nearly nine times the combined searching effort compared to the combined effort accorded the North and East.

Table 1. Indexes of relative abundance (lbs/hr) on varying spatial and temporal scales.

	Shore/Quadrat				**Island**
Seasonal Period	**South**	**West**	**North**	**East**	**Oahu**
Pre	1,752	4,048	0	0	2,352
Peak	4,784	18,538	5,333	2,096	11,386
Fishing Season					
2014	4,227	16,560	3,330	2,000	9,861

Two significant correlations were found in this study. The first was between the trip catch (lbs) and total effort (hrs) from the fishermen aboard the vessel. Each dataset contained 24 samples and were normally distributed according to a Kolmogorov-Smirnov (K-S) test for normality. The resulting Pearson correlation coefficient was $r=0.72$, with a single-tailed p-value = 0.00004. The second significant correlation was between the pilot biomass estimates (lbs) and the resulting CPUE (lbs/trip). Both datasets had a sample size of 24 and were normally distributed according to a K-S test for normality. The resulting Pearson correlation coefficient was $r=0.38$, with a single-tailed p-value of 0.04.

Discussion

To the authors' knowledge, this study is the first to utilize aerial spotter derived information for the development of abundance estimates for any fishery within Hawaiian waters. Akule represent an ideal test species because of their predictable near-shore schooling behavior around the island of O'ahu. Aerial spotting for fishing operations already exist for this fishery providing the potential for relatively easy and inexpensive data acquisition once the fishermen and pilot have been trained in the scientific methods required.

The strong positive correlation (p-value < 0.01) between fishermen trip catch (lbs) and effort (hrs) suggests a stable population of akule surrounding O'ahu. As the fishermen put in more effort, they catch more fish. This agrees with the initial stock assessment of low to moderate exploitation of akule for all of Hawai'i (Weng and Sibert 2000). An overexploited population might not yield such increased catch levels with greater effort.

Another relationship seems to be evident between the aerial biomass estimates (lbs) and the corresponding CPUE (lbs/trip) by the fishermen. The correlation between these two variables yielded significant results at the p-value <0.05 level. A small sample size restricted the power of this correlation but the observed positive relationship remains clear. The connection between aerial survey biomass estimates and CPUE suggest the potential for effective abundance estimates. This supports the further use of direct observation via aerial spotters to create a more sensitive time series for relative abundance.

The total schools spotted and index values in this study seem to agree with the previously discussed historical catch of akule around O'ahu. Spotted schools and catch are highly concentrated in the western and southern waters. Index levels in these areas remained high when standardized with search times. However, the northern and eastern waters received relatively little search effort. It cannot be discerned from this study the degree to which these areas vary in population. Many spotted schools in the East were not represented in the index calculations because of missing GPS tracking data. More sampling is required to provide equal sampling effort in all quadrats before conclusions on spatial abundance can be made.

The initial index values will provide the baseline for comparison in future years. Once a time series has been established, trends can be compared with CPUE based estimates. This approach will hopefully alleviate the different biases introduced by each unique method (Lo et al. 1992; Pitcher 1995).

Comparing trends in both fishery-dependent and –independent based abundance estimates will provide the best information for managerial needs in the future (Barnes et al. 1992).

Assuming the accuracy of the spotter pilot, this study shows that surround gill net fishing does not decimate the target school of akule. The practice typically harvested around 14% of the fish directly observed from the air. This fact should help alleviate concerns raised over the complete harvest of entire schools.

Schools of akule tend to reform in close proximity to the previous day. Fishermen often target a school in the morning that was spotted the day before. The same aggregate of fish might also be fished multiple times, over many days as it reforms (Pers. Comm. Kaipo Miller, commercial fisherman June 1, 2015). These accounts are supported by a tag and release study that found little movement among individual akule around O'ahu (Kawamoto 1973). This fact may result is the same schools being spotted multiple times during a survey period. It should be noted that this study utilized inshore hand liners to catch the fish rather than surround nets. Larger sample sizes will help moderate potential bias introduced with double counts.

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