Combining seabird diet, acoustics and ecosystem surveys to assess temporal variability and occurrence of forage fish

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ABSTRACT

The abundance and distribution of Northern anchovy (*Engraulis mordax*) and young of the year (YOY) rockfish (*Sebastes spp.*) are critical for the survival and reproduction of seabirds, mammals, and predatory fish within the California Current Ecosystem. Traditional detection and quantification of forage fish by trawling can be time consuming and expensive, and may not provide the spatio-temporal resolution needed to examine ecological relationships in quickly-changing marine environments. In an effort to accurately sample forage fish with less expense and higher resolution, this study combined seabird diet and acoustic descriptors to quantify anchovy schools and YOY rockfish in hydroacoustic surveys conducted between 2004 and 2015. Anchovy-like schools were selected from echograms assuming a volume backscattering strength (S_v) range of -47.6 to -42.9 dB. YOY rockfish-like single targets were selected considering a target strength (TS) range between -52.8 to -50.9 dB, calculated from a lengths of fish consumed locally by three piscivorous seabirds. Acoustics indices of forage fish were significantly correlated with abundance catches from trawl data collected from an ecosystem assessment survey and relative abundance estimated from breeding seabird diet data. Inter-annual and seasonal indices of forage fish indicated strong anchovy occurrence during 2004-2008 and increased YOY rockfish from 2011-2015. These observations confirm previously described changes in upwelling and forage fish variability off central California. Importantly, these results provide new information on the spatio-temporal variability of the vertical and cross-shelf distribution of anchovy schools and will benefit the design of habitat preference models for anchovy and predators. To verify the acoustics, indices were compared to trawl data from an ecosystem assessment survey and relative abundance estimated from seabird diet data collected from locally-breeding piscivorous seabirds. Results add to the existing knowledge of how these species distribute in the water column, and with regards to anchovy provide insight on how they distribute across the shelf in opposing ocean phases. In addition, acoustic indices derived for both forage fish species showed a significant coherence with both the trawl surveys and seabird diets. Combining acoustic methodologies with trawl data and predator diet can be used to monitor distribution and temporal variability of forage fish species to benefit conservation of top marine predators.

Keywords: hydroacoustic, acoustic abundance, anchovy, rockfish, seabirds, target strength

1. Introduction

Forage fish are an important link between primary producers and higher trophic level predators in pelagic ecosystems (Cury et al. 2000; Pikitch et al. 2014). In upwelling systems, forage fish availability can determine reproductive success and survival of many upper trophic level species (Cairns et al. 1987; Ainley et al. 1993). Forage fish abundance fluctuations often display complex variability that is linked to inter-decadal variability of ocean-climate conditions (e.g., ENSO), such as the well-documented sardine and anchovy regime shifts throughout the world's eastern boundary current ecosystems (Chavez et al. 2003; Bertrand et al. 2008; Schwartzlose et al. 1999). Moreover, the abundance and spatial distribution of these fish is highly variable over shorter time scales, due to a tight coupling with time-varied physical oceanographic processes driving zooplankton and phytoplankton abundance (Vlietstra 2005; Ayón et al. 2008; Swartzman et al. 2008).

A key feature displayed by many forage fish species is their tendency to form dense aggregations, or schools during the day and then disperse towards the surface at night to feed (Pitcher and Parish 1993; Fréon et al. 1996; Fréon and Misund 1999; Kaltenberg and Benoit-Bird 2009). The spatio-temporal variability of forage fish aggregations are critical to the foraging of dependent predators and important to fisheries and ecosystem management (Cairns 1987; Sydeman et al. 2001; Hilborn 2011; McClatchie et al. 2016), but create challenges in assessing their abundance and patchy distribution patterns with typical trawl surveys. Acoustic-trawl surveys are frequently used to provide insight into forage fish abundance and distribution at large spatial scales in support of population assessment and management (Mais 1974; Barange et al. 1999; Simmonds et al. 2009; Zwolinski et al. 2012). However, such surveys typically estimate abundance at the fish stock or ecosystem level, often with a single survey in any given year, and rarely describe distributions at finer spatial scales (e.g. 10s of km) or across seasons, which may be relevant to understanding interactions with central place (or other) foragers (Churnside et al. 2009). Therefore, acoustic surveys implemented at finer spatial and greater temporal resolution may provide more effective means of evaluating the spatial and temporal variability in forage resources relative to dependent predators.

The California Current Ecosystem (CCE) is a highly productive upwelling system, where seasonal winds stimulate upwelling of cold nutrient-rich water, resulting in a rich coastal food web (Checkley and Barth 2009). In the marine food-web off central California, northern anchovy (*Engraulis mordax*) and YOY rockfish (*Sebastes spp.*) play a pivotal role in the overall success of upper trophic level predators (Miller and Sydeman 2004; Ainley et al. 2015; Szoboszlai et al. 2015). Ocean-climate events strongly influence the regional abundance and availability of northern anchovy and YOY rockfish species in the central California Current (Chavez et al. 2003; Santora et al. 2014, 2017). Further, mid-water trawl surveys indicate that northern anchovy tend to display higher relative abundances in years when upwelling is weak, while YOY rockfish display higher abundances when ocean temperature is cool and upwelling is strong (Santora et al. 2014; Ralston et al. 2015). However, this time series is limited in seasonality, and does not survey the entire range (particularly the nearshore margin, shoreward of approximately 50 m bottom depth) of the anchovy stock. Therefore, finer-scale hydroacoustic surveys may provide an effective way of overcoming some of the difficulties posed by the biological and external environmental factors that drive forage fish abundance and variability (Barange et al. 2009).

While acoustic studies of krill, also a key forage species that display dense aggregations, are developed in the CCE at high spatial resolutions (Santora et al. 2011; Manugian et al. 2015), acoustic studies describing northern anchovy or YOY rockfish aggregations are not yet available and would aid in better understanding the availability of forage fish to central place foragers. Therefore, combining multiple sampling techniques, involving acoustics, trawl estimates and predator diet, may provide a more complete picture of northern anchovy and YOY rockfish populations, including consistencies or lack thereof among these very different sampling methods (Churnside et al. 2009; Zwolinski et al., 2012).

Seabirds are conspicuous predators of marine environments and are sensitive to changes in ocean-climate and availability of prey (Ainley et al. 1995; Furness and Camphuysen 1997; Sydeman et al. 2001; Vlietstra 2005; Santora et al. 2014). Seabird demographic parameters are important indicators of forage fish availability (Piatt et al. 2007) and successful reproduction is dependent on the abundance and availability of forage species near their colony (Cairns 1987; Cury et al. 2000). Moreover, seabird diet provides information on the timing and abundance of forage fish species occurrence, making them useful indicators of forage fish availability. In the Gulf of the Farallones, northern anchovy and YOY rockfish between 1.7 and 21 cm in length are the preferred prey items for many breeding seabirds (Ainley et al. 1993; Elliott et al. 2016), and previous studies have demonstrated strong correlations between fishery survey abundance estimates and the fraction of preferred prey in diets (Mills et al. 2007).

Herein, we conduct an assessment using a combination of seabird diet, hydroacoustics, and night-time mid-water trawl surveys, to evaluate the seasonal and inter-annual variability of the occurrence of relative forage fish abundance and distribution off central California. We quantify acoustic descriptors designed to classify forage fish schools and determine the presence of anchovy-like schools and YOY rockfish-like single targets during 2004-2015. *TS* methods rather than S_v methods were used to classify YOY rockfish, due to the lack of sufficient details describing acoustic aggregations of YOY rockfish. Specifically, we test the hypothesis that acoustic-derived estimates, as indicated by anchovy-like density measurements and population counts of YOY rockfish-like single targets, will reflect known variability of anchovy and YOY rockfish abundance as indicated by independent mid-water trawl surveys and the diet of three seabird species. Our objectives were to: (1) assess the relative acoustic density of northern anchovy and abundance of prey sized YOY rockfish; 2) examine seasonal and inter-annual trends in the relative acoustic density of northern anchovy and prey sized YOY rockfish; and 3) compare the relative acoustic fish estimates with independent metrics from night-time trawl surveys and seabird diet studies. We discuss how our assessment benefits the monitoring distribution of forage fish species off central California and how the results provide new opportunities for studying the foraging ecology of seabirds breeding on the Farallon Islands relative to their temporal and spatial distributions.

2. Methods

2.1 Geographical setting and study area

The Farallon Islands, located within the Gulf of the Farallones off central California, are home to the largest seabird colony in the continental U.S. south of Alaska (Ainley and Boekheilde 1990). Located on the continental shelf and adjacent to a steep shelf-break, the archipelago comprises 50 hectares of critical breeding and resting habitat for seabirds and pinnipeds. Other important geomorphic features include Cordell Bank, a seamount comprised of rocky reef and other hard substrate habitat, and the Point Reyes headland, which together influence ocean currents and biological activity in the region (Chin et al. 1997; Ryan et al. 2010; Santora et al. 2012). The continental slope to the west of Farallon Islands is characterized as highly irregular bathymetry and dissected by submarine canyons and gullies that begin at the shelf break, providing a diverse complex of marine habitats (Chin et al. 1996; Santora et al.; 2012). During the upwelling season, cold nutrient rich waters are retained on the lee side of prominent headlands resulting in upwelling shadows (Wing et al. 1998), and a high concentration and retention of phytoplankton, zooplankton, forage fish, seabirds and marine mammals (Largier et al. 2006; Ryan et al. 2010; Santora et al. 2012).

The Farallon Islands and Cordell Bank are key features of a highly unique ecosystem and serve as the center points of the Greater Farallones (GFNMS) and Cordell Bank (CBNMS) National Marine Sanctuaries. We analysed hydroacoustic data collected by the Applied California Current Ecosystem Studies (ACCESS; www.accessoceans.org), a partnership between Point Blue Conservation Science (Point Blue), GFNMS, and CBNMS. ACCESS implements an annual sampling scheme designed to monitor marine birds and mammals, fish and zooplankton abundance, and surface and water column properties within the sanctuaries during daylight hours. Data included in this study were collected from April - October, 2004 - 2015. Fixed East-west transect lines (n=7) were sampled, and spanned the continental shelf and slope region (defined by the 20 m to the 1000 m isobaths, respectively), covering the offshore area between Bodega Bay (38.3° N) and San Pedro Rock (37.6° N) (Figure 1).

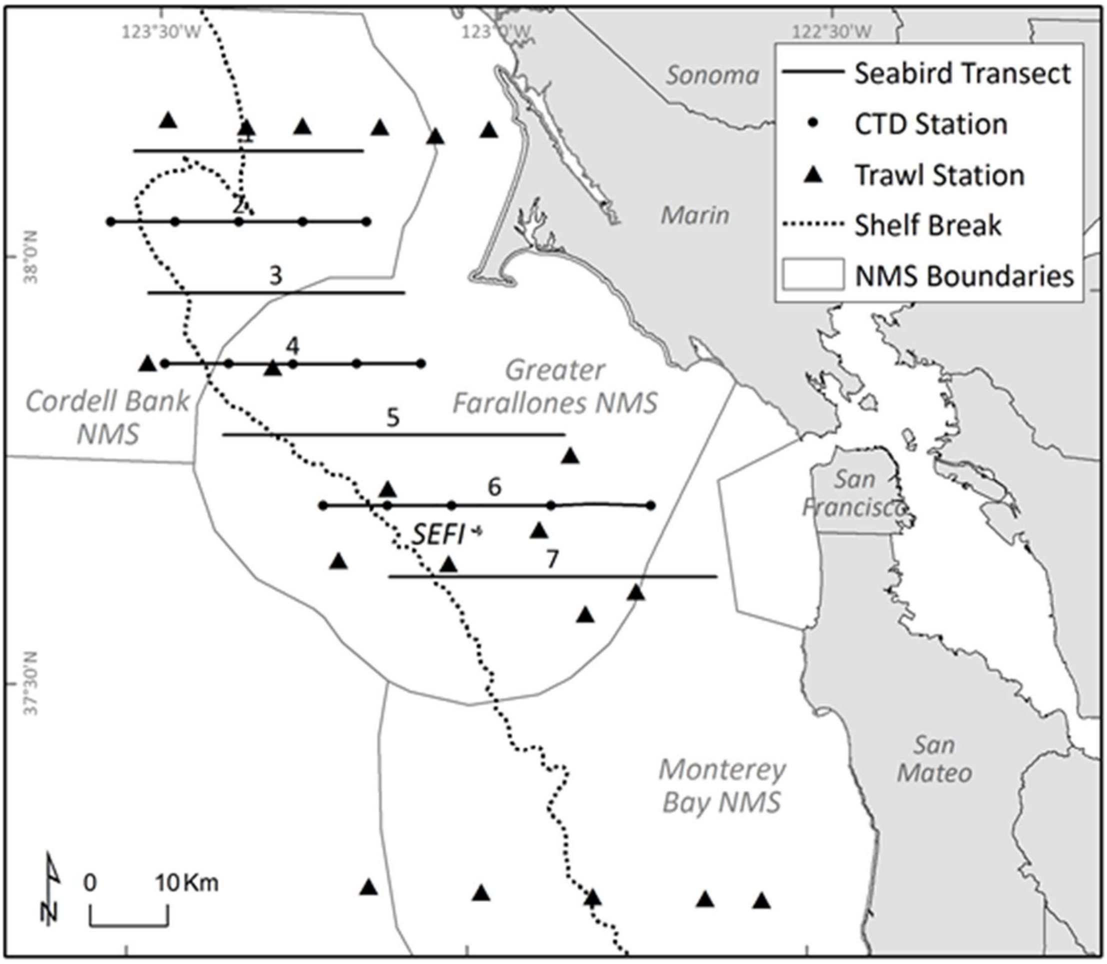

Figure 1. Map showing the study area including seabird transect lines and oceanographic stations visited by the Applied California Current Ecosystem Studies (ACCESS), the location of Southeast Farallon Island (SEFI), and trawling stations visited by the Rockfish and Recruitment Ecosystem Studies cruises in their core study area in central California (NOAA-NMFS).

2.2 Fish sampling using seabird diets

Seabird diet was collected on the Southeast Farallon Island, Farallon National Wildlife Refuge, from three piscivorous seabirds: common murre (*Uria aalge)*, rhinoceros auklet (*Cerorhinca monocerata*), and Brandt's cormorant (*Phalacrocorax penicillatus*). Data collection methods differed amongst species. Common murre diet were collected 4-5 times weekly during the chick rearing period from 2000-2015 (Roth et al. 2008). The murre chick rearing period lasts approximately 4 to 6 weeks beginning when chicks hatch in late May and ending when most chicks have departed the colony in late June or early July (Roth et al. 2008). During two-hour observation periods, feeding frequency and diet composition of chicks were recorded to the lowest possible taxon based on morphological characteristics and location of the fins (Miller and Lea 1972; Sydeman et al. 2001; Miller and Sydeman 2004; Roth et al. 2008). The size of each prey item was visually estimated relative to the gape length and transformed to standard length (see Roth et al. 2008 for details). Rhinoceros auklet diet was collected weekly using mist nets to capture auklets returning to provision their young during June to July. Fish dropped from their bill were collected, measured for standard length and identified to species (Thayer and Sydeman 2007). Brandt's cormorant diet was determined from regurgitated pellets collected from three main breeding sites on the island (Elliott et al. 2015, 2016). Pellets were dissected for fish otoliths, and were measured and identified to the lowest taxonomic level possible. Species-specific regression equations were applied to otolith measurements to estimate prey lengths (Elliott et al. 2015, 2016).

2.3 Hydroacoustic data collection and processing

Hydroacoustic data were collected aboard three research vessels: R/V John H. Martin (17 m), Ship McArthur II (60 m), and R/V Fulmar (20 m). Each vessel used in this study was equipped with multi-frequency split-beam echo-sounders (Simrad EK-60) with an array of 38, 120, and 200 kHz transducers (calibrated each spring using a 38.1 mm tungsten carbide sphere) (Demer et al. 2015). Acoustic absorbance (Francois and Garrison 1982) and sound speed (Mackenzie 1981) used in acoustic processing were calculated for each monthly survey using mean temperature and salinity in the top 25 m of the water column found from CTD casts. Vessel speed was approximately 10 knots (5.2 ms) during surveys, and the echo-sounders synchronously transmitted 1.024 ms pulses vertically through the water column. To sample forage fish, data were collected every 2 seconds along transects, with raw data captured from the minimum depth of the transducer face to at least 300 m. To avoid potential surface noise (e.g. wave generated bubbles) and to account for near field effects, the upper 5 m of the water column were excluded from analysis. In addition, we excluded processing in a zone of 2 - 5 m from the bottom in a manual process that depended on degree bottom depth variability. This method was designed to exclude strong bottom echoes from rocky substrate and pinnacles that intermingled with biological signals and could not be separated. Acoustic data captured during off transect periods, such as when oceanographic and zooplankton data were being collected, were also removed from analysis. Acoustic data consisted of: volume backscattering strength (S_v) (dB re 1 m^{-1}), which is a measure of the total amount of sound backscattered from 1 m^3 of water, and target strength (*TS*) (dB re 1 m^2), representing the amount of sound backscattered by a single target based on its material properties and orientation. Acoustic data collection time and location were indexed using a GPS input into the echo-sounder.

Acoustic data for each cruise were independently uploaded and analysed using the program Echoview Version 7 (Echoview Software Pty Ltd, Hobart, Tasmania, Australia), which visualizes raw acoustic data into absolute measurements of backscatter for analysis. With all acoustic data collected at sea, there is associated background noise which can't be attributed to biological organisms or other water column sources. Background noise was reduced by generating and subtracting time varied noise from all raw S_v and *TS* echograms (Hewitt et al. 2004). The level of noise reduction was adjusted by visually comparing echograms until the signal to noise ratio (SNR) at depth appeared to be equal (Hewitt et al. 2004).

2.4 Acoustic anchovy-like school detection

To discriminate potential fish aggregations from zooplankton a dual frequency analysis was conducted between $S_{v120\mathrm{kHz}}$ and $S_{v38\mathrm{kHz}}$. Fish with swim bladders tend to display as intense scattering features at $S_{v38\mathrm{kHz}}$, while zooplankton tend to display as intense scattering features at $S_{v120\mathrm{kHz}}$ (Fielding et al. 2012). By selecting a dB difference of S_v 8-23 dB between the two frequencies, we were able to positively mask, bin, and remove a considerable number of scattering features from the $S_{v38\mathrm{kHz}}$ data that could not be attributed to fish aggregations (Manugian et al. 2015). The resulting echogram was then restricted with a S_v threshold range between -60 and -38 dB, to remove low intensity targets such as plankton layers and to avoid incorporating non-linear acoustic effects that results in multiple scatters from an individual target within densely packed schools, respectively. The S_v maximum threshold level of -38 dB was manually selected by examining densely packed schools for each cruise and year independent from one another. We then detected acoustic schools by using the "school detection module” to make measurements of acoustic descriptors. The module uses algorithms derived from the Shoals Analysis and Patch Estimation System (SHAPES) (Barange 1994; Coetzee 2000). The algorithms consider the echogram as a matrix of energy backscatter measurements and acoustic samples. It then examines the data for contiguous acoustic samples spatially based on user defined minima. We first set morphometric parameters based on school length and height. A minimum school length was set at 10 m with a minimum candidate length of 5 m. Minimum school height was set at 3 m with a minimum candidate height of 2 m (Lawson et al. 2001; Kaltenberg and Benoit-Bird 2009). The module then draws an ellipse around contiguous data points to identify schools meeting the length and height criteria (Lawson et al. 2001; Vlietstra 2005). In order for schools in close proximity to each other to be linked as one, they had to meet linking distance criteria, which was set at 20 m horizontally and 10 m vertically (Lawson et al. 2001; Kaltenberg and Benoit-Bird 2009). In some survey years, the module detected large indeterminate aggregations, likely representing low intensity plankton and fish scattering layers. These aggregations were considered not to be acoustic fish schools and were removed from the analysis (Lawson et al. 2001). Schools that met these criteria were classified as fish schools, and their acoustic descriptors were exported for further analysis.

Anchovy behaviour and schooling morphology have been found to vary enough from other similar schooling species that it is possible to discriminate between them using a variety of acoustic descriptors (Haralabous and Georgakarakos 1996; Lawson et al. 2001; Robotham et al. 2010). Mean S_v is one acoustic descriptor that aids in the discrimination of anchovy, from other schooling species such as sardine (*Sardinops sagax*), and round herring (*Etrumeus whiteheadi*) (Lawson et al. 2001). S_v aids in discrimination due to the schooling characteristics of the observed species and its' subsequent energetic response (i.e. mean S_v). Using discriminate function analysis, Lawson et al. (2001) found that anchovy had a S_v mean of -42.8 dB (SE ± 0.69) within a region of the Benguela Current. However, we found that using an upper threshold of S_v -38 dB excluded the densest regions of schools, and shifted the S_v properties of these schools by an average of -2 dB. For this reason, we derived a 99% Confidence Interval (CI) around the S_v mean of -44.8 dB (SE ± 0.69), and used a S_v range of -47.6 to -42.02 dB to select a subset of schools meeting these criteria. With the understanding that anchovy are not the only schooling fish species in the CCE and the lack of collaborative net samples, we made an effort to visually confirm anchovy schools in the raw echograms by using the following definition: acoustic anchovy fish schools are described as strong scattering features that display discrete and continuous edges and which are distinct from loosely aggregated fish layers (Kaltenberg and Benoit-Bird 2009), and are pelagic (e.g. showing a clear distinction between the school and the seafloor). If detected schools met both the S_v and physical characteristics, they were classified as anchovy-like and were selected for further analysis. The acoustic school classification process for anchovies was repeated separately for each cruise and enumerated all schools detected. The following school descriptors were exported: nautical area scattering coefficient (s_A), height, length, depth, bottom depth, survey effort, skewness, and kurtosis of each school in each survey. s_A is a measure of density which provides an indication of relative abundance (Kaltenberg and Benoit-Bird 2009) and is defined as square meters per square nautical mile (m^2 nmi^{-2}) (Maclennan et al. 2002). Furthermore, to provide spatial context anchovy-like school distribution was mapped.

2.5 YOY rockfish-like target detection and classification

Following the methods for anchovy-like schools, we first conducted a dual frequency analysis between $S_{v120kHz}$ and S_{v38kHz} to remove zooplankton. The resulting echogram was converted into a single targets echogram, wherein single targets are represented as a peak in *TS* (dB). In order to classify single targets as YOY rockfish, a length range based on the 95% CI of YOY rockfish lengths observed in seabird species diet was used to calculate a *TS* range. Estimation of YOY rockfish TS values were calculated using the following length dependent model: TS_{38kHz} = 20 x Log10 (L) – b; where L is the standard length of the fish and b (-67.7) is a species-specific value for the intercept (Kang and Hwang 2003; Simmonds and MacLennan 2005). The coefficient b in the model, is determined by a least-squares fit of the mean TS against the individual fish lengths (Kang and Hwang 2003). This equation provides a curved distribution of the mean *TS* against the fish lengths of rockfish species that matches the *TS* of rockfish in ex-situ experiments (Kang and Hwang 2003). The resulting target strength range of -52.8 to -50.9 dB is fairly narrow compared to the range of TS that a single live fish may exhibit at different orientations , however by restricting our *TS* range to this we are less likely to mistakenly classify non-rockfish targets (see Method Caveats).

For a peak to be considered a single target, we first defined the pulse envelope with the following criteria: 1) we set a peak *TS* threshold of -70 dB based on the values generated from the length dependent model; 2) we used a 6 dB pulse length determination level, which is the number of decibels below the peak that determines the pulse envelope; 3) the pulse length was normalized by taking the received pulse length and dividing by the transmitted pulse length, and then assigned a minimum of 0.6 and a maximum of 1.5; 4) we then corrected for transducer directivity by selecting a maximum beam compensation of 6 dB; and 5) to ensure all point scatters were within the measured pulse length contributing to a single target, all measured samples had to be within 0.6 standard deviations of the major and minor axis angles. If the target met these criteria, it was exported into a database for calculating total targets detected for each survey. The process of single target detection for YOY rockfish-like targets was repeated for each cruise and effort was recorded in the form of nautical miles (nmi) surveyed. Detected single targets were then summed in the following depth layers: 5 to 15 m, 15 to 25 m, 25 to 35 m, 35 to 45 m and 45 to the maximum depth. Individual YOY rockfish-like targets were not mapped because they were too numerous.

2.6 Acoustic considerations and fish life-history

The acoustic methods for anchovy-like school classification are restricted to densely-packed schools observed during day light hours. Variability in school density is expected however schools outside of our anchovy detection S_v range could bias our results low. False-positive identification and the inclusion of mixed species fish schools are also possible, and maybe biasing our indices (Lawson et al. 2001). Lawson et al. (2001) estimated that using S_v as a primary descriptor for discriminating between species during day light hours had a success rate of 80.8%. However, the life-history of other abundant fishes in the Gulf of the Farallones may minimize false positive classification. The other two fish species with catch abundances in the same order or magnitude as anchovy (and YOY rockfish) are YOY Pacific hake and YOY Pacific sanddab (Sakuma 2017). The Pacific sanddab is benthic-oriented beyond the larval phase (Sakuma and Larson 1995), when their size (and therefore potentially their target strength) might overlap with YOY rockfish. Pacific hake may form dense daytime schools, but avoid light during the day (Alverson and Larkins 1969; Bailey et al. 1982) making their distribution deeper than typical daytime anchovy schools (ranging from the surface to less than 200m; Mais 1974), and likely more pelagic than much of our shelf-habitat study area. The Pacific sardine may form schools that acoustically resemble anchovy schools (Lawson 2001; Kaltenberg and Benoit-Bird 2009), and indeed may be the largest source of fish school misclassification error in our study, however sardine schools are described by mean S_v values over an order of magnitude higher (Lawson 2001). Typical adult and larger juvenile sardine schools should then be excluded by our S_v range filter. Furthermore, sardine catch abundance was more than an order of magnitude less than anchovy during the period of our study (Sakuma 2017).

Individual target strength data is highly susceptible to the angle of incidence of a fish in an acoustic beam. The slightest tilt in angle can result in a drastically different TS when compared to a mean range calculated from a length dependent model (Kang and Hwang 2003; MacLennan & Simmonds 2013). Therefore, using the entire range of TS envelopes that our target species are capable of producing is not practical in an environment with such high diversity of fish species. The TS range selected was not meant to have a high classification rate, but rather relied upon the broad spatial coverage of the acoustic data, and the relatively high abundance of YOY rockfish compared to other similarly sized species (Sakuma 2017). Furthermore, the TS range selected was meant to gather a representative sample of the populations available to the seabirds as prey. Following this approach may have also resulted in an underestimation of relative abundance, especially of smaller YOY rockfish earlier in the season (as YOY rockfish grow rapidly following parturition in the winter of any given year). We acknowledge this restrictive approach excludes many juvenile rockfish from our analysis.

2.7 Ecosystem assessment surveys

Catch data on YOY rockfish and anchovy were derived from the NOAA-NMFS Rockfish Recruitment and Ecosystem Assessment trawl surveys conducted off central California (Ralston et al. 2013; Sakuma et al. 2016). Surveys were conducted in May and June during the night using a modified Cobb mid-water trawl. Trawl samples were taken 2-3 times per year and for 15 minute durations at each trawling station in each study region (Figure 1). The catch data from the core region overlaps with our study area and were used for comparison with the relative acoustic fish abundance estimates from this study. The number of trawling tows ranged between 12 in 2008 to 42 in 2007, with an average of 28 tows being conducted per year. NOAA-NMFS standardized abundance (catch-per-unit-effort; CPUE) indices for anchovy and YOY rockfish were calculated relative to the average catch (log+1 transformed) for surveys conducted from 2004 to 2015.

2.8 Analysis

Relative abundance estimates derived from the seabird diets served as an independent set of data to test whether a Pearson correlation existed with estimates derived from the acoustic analysis. Diet composition for each species was calculated and chi-squared tests were performed to examine differences in anchovy and YOY rockfish consumption between years. Length frequency distributions of fish consumed by each seabird species were calculated to provide context on variability of fish size selected by seabirds. Analysis of Variance (ANOVA) tests were conducted to examine differences in lengths of fish consumed by seabirds between years and among species. Relative acoustic fish abundance estimates were scaled for anchovy-like s_A and YOY rockfish-like single targets relative to sampling effort in nautical miles for each cruise. The indices were calculated as the mean s_A nmi^{-1} of anchovy-like schools and mean number of single targets nmi^{-1} of YOY rockfish-like targets during April to July. This time period overlaps the time at which the NOAA-NMFS surveys occur (Figure 1), and the time when breeding seabirds deliver fish to chicks at SEFI. Seasonal and inter-annual trends were examined in anchovy-like s_A relative to effort and amongst the other exported school descriptors. ANOVA tests were performed to test for significant differences in s_A, depth of the schools and associated bottom depth between years and months. Regression analysis was used to assess for linear and non-linear trends between s_A relative to year and month. We then examined overall seasonal and inter-annual trends in the effort-corrected number of YOY rockfish-like single targets. ANOVA tests were performed to assess significant differences in total number of YOY rockfish-like targets (per nmi^{-1}) between years and months, and regression analysis to assess for linear and non-linear trends in YOY rockfish-like targets nmi^{-1} across years and months.

The independent observations of seabird diet, acoustics, and mid-water trawl surveys allow for the evaluation of forage fish availability and specifically, the efficacy of using acoustics to monitor forage fish. Standard anomalies of acoustics were calculated and compared with indices from the mid-water trawl survey and seabird diets. Anomalies were calculated by subtracting the long-term mean from each year’s average and dividing it by the standard deviation. Anomalies of anchovy and YOY rockfish from mid-water trawls surveys were derived from Sakuma et al. (2016). Seabird diet data time series are represented by the proportion of anchovy and YOY rockfish in the diets of common murre, rhinoceros auklet and Brandt's cormorant for each year. Pearson correlation was used to compare the relative acoustic fish abundance standardized anomalies with mid-water trawl and seabird diet anomalies. We used regression and multi-regression analyses to determine what proportion of the variability observed in the mid-water trawl surveys and seabird diet anomalies could be explained by the relative acoustic fish abundance anomalies. Analyses were conducted separately for anchovy-like acoustic densities and prey sized YOY rockfish-like relative abundance estimates.

3. Results

3.1 Fish sampling using seabird diets

Anchovy and YOY rockfish were the predominant fish species observed in the seabird diets, however we found significant annual differences in the proportions consumed by common murre ($\chi^2 = 19{,}872$, df = 11, $p < 0.001$), Rhinoceros auklet ($\chi^2 = 1{,}549$, df = 11, $p < 0.001$), and Brandt's cormorant ($\chi^2 = 13{,}835$, df = 9, $p < 0.005$) (Figure 2).Anchovy was the dominant prey from 2004 to 2008, and accounted for approximately 60% to 96% of the birds' diets during this time period. YOY rockfish accounted for approximately 6% to 97% and was the dominant prey from 2009 to 2015. Pacific Saury (*Cololabis Saira*) was a primary prey in the rhinoceros auklet diet from 2009 to 2012, and sanddabs (*Citharichthys spp.)* in Brandt's cormorant diet in 2011 and 2012.

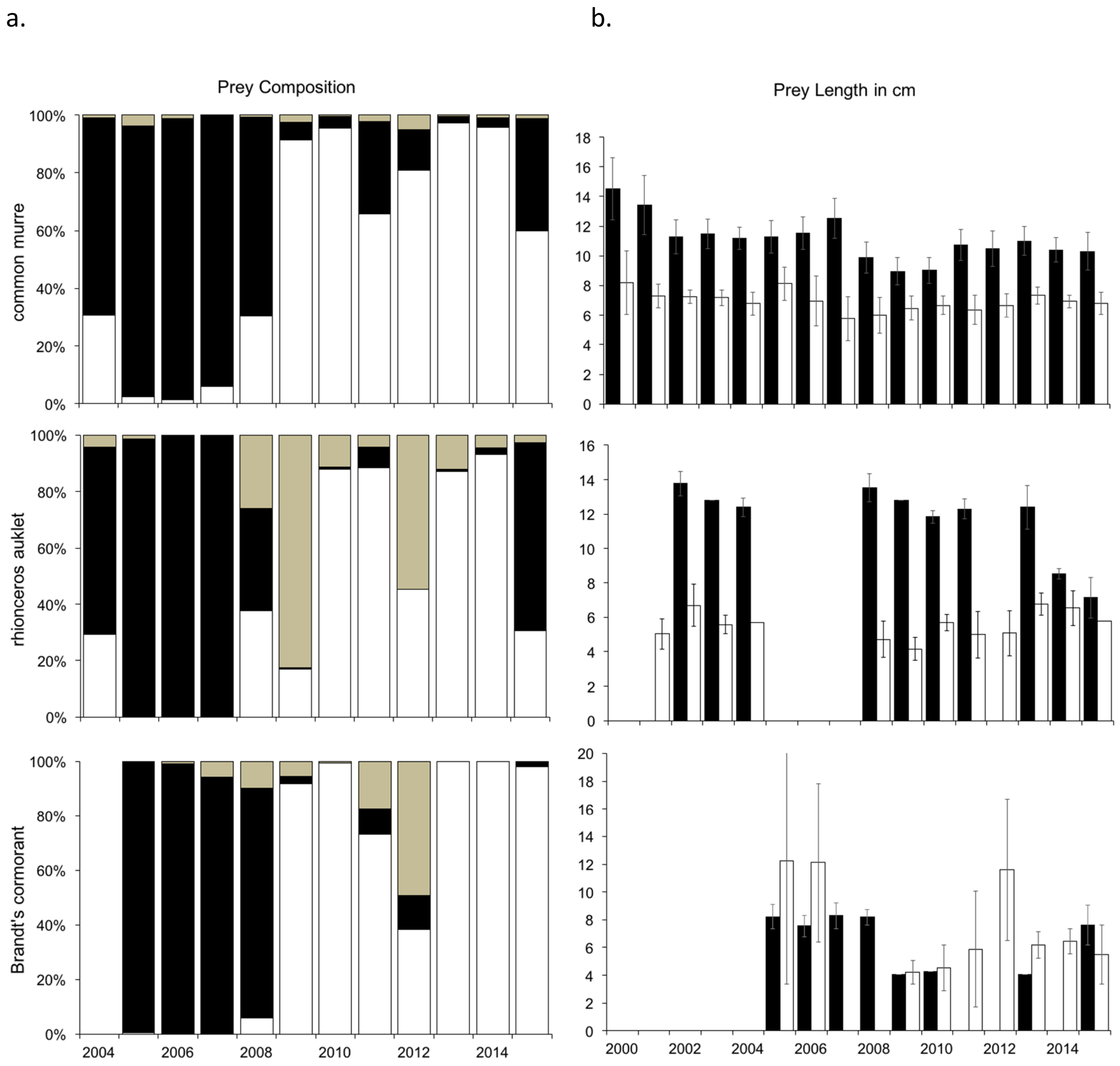

Figure 2. Diet composition for common murre, rhinoceros auklet, and Brandt's cormorant by year are depicted in the figures labeled (a). White bars represent juvenile rockfish, black represents anchovy, and grey represents all other prey consumed. Figures labeled (b) represent prey sizes (±SE) consumed by the seabirds by year. Years without bars represent years where anchovy and juvenile rockfish were not present in the diet of the birds. No data was collected for Brandt's cormorant in 2000 and 2001.

There were significant differences in the size of anchovy and YOY rockfish consumed among years (ANOVA: $p < 0.001$) and YOY rockfish were significantly smaller in size than anchovy for all seabirds (Table 1, ANOVA).

	Prey Length							
Bird species	**Length 95% CI YOY rockfish**	**N**	**Mean**	**±SE**	**Length 95% CI northern anchovy**	**N**	**Mean**	**±SE**
Common murre	6.92 to 6.94	27,775	6.93	0.004	11.43 to 11.5	10,159	11.38	0.02
Rhinoceros auklet	5.57 to 5.75	996	5.89	0.03	12.59 to 12.79	614	12.69	0.05
Brandt’s cormorant	5.74 to 6.01	1,172	5.88	0.06	7.86 to 8.24	146	8.06	0.09

	ANOVA		
	df	**F**	**P <**
Common murre	39,925	86,080.8	0.001
Rhinoceros auklet	2,167	1,820.8	0.001
Brandt’s cormorant	1,318	59.8	0.005

Table 1. Provides 95% CI’s of YOY rockfish and northern anchovy sampled in the three seabirds’ diets, number of samples collected, the mean length, and the standard error. The bottom left of the table shows the ANOVA results showing that YOY rockfish were significantly smaller in size than northern anchovy consumed by the birds.

To estimate an appropriate *TS* value for YOY rockfish, a mean length range of 5.57 to 6.94 was input into the length dependent model described in the methods, which output a *TS* range between -50.9 to -52.8 dB. While the fish length range used is tighter than would have been expected if using all observed intra and inter-annual variability in YOY rockfish length, it provides a narrow *TS* range for acoustic detection of prey-sized fish.

3.2 Acoustically observed anchovy schools

The school detection process resulted in 39,494 aggregations identified, 1,551 met the S_v requirement to be considered for visual inspection, and 208 schools passed the visual confirmation (Table S.1, Figures 3 and 4). Some schools, while still conforming to the visual description, formed complex assemblages that covered large spatial areas (Figure 4).

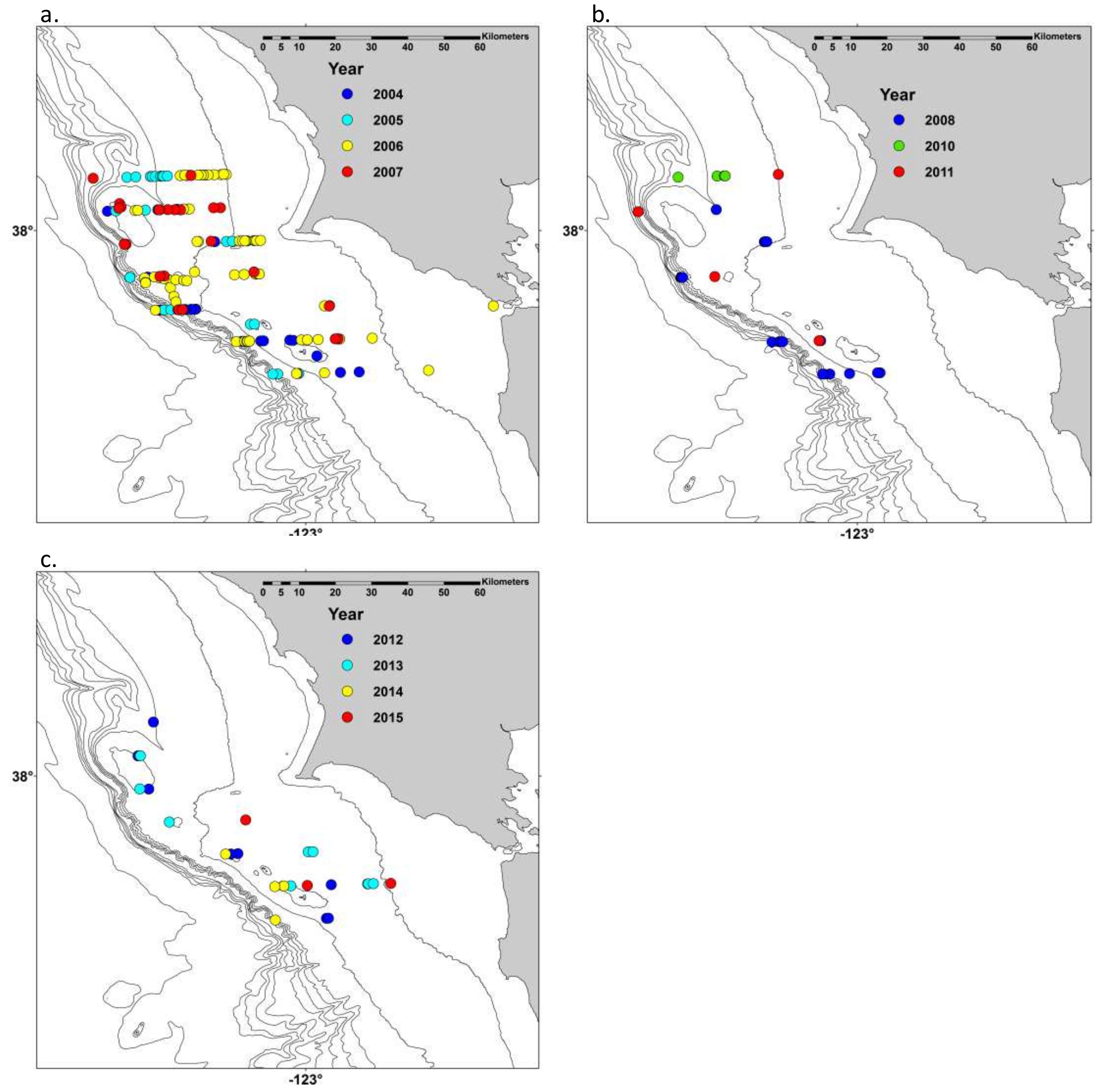

Figure 3. Spatial distribution of detected anchovy-like schools (n=208) partitioned into 3 time periods for clear viewing, ranging from schools detected during (a) 2004-2007, (b) 2008-2011 (no schools were detected in 2009), and (c) 2012-2015.

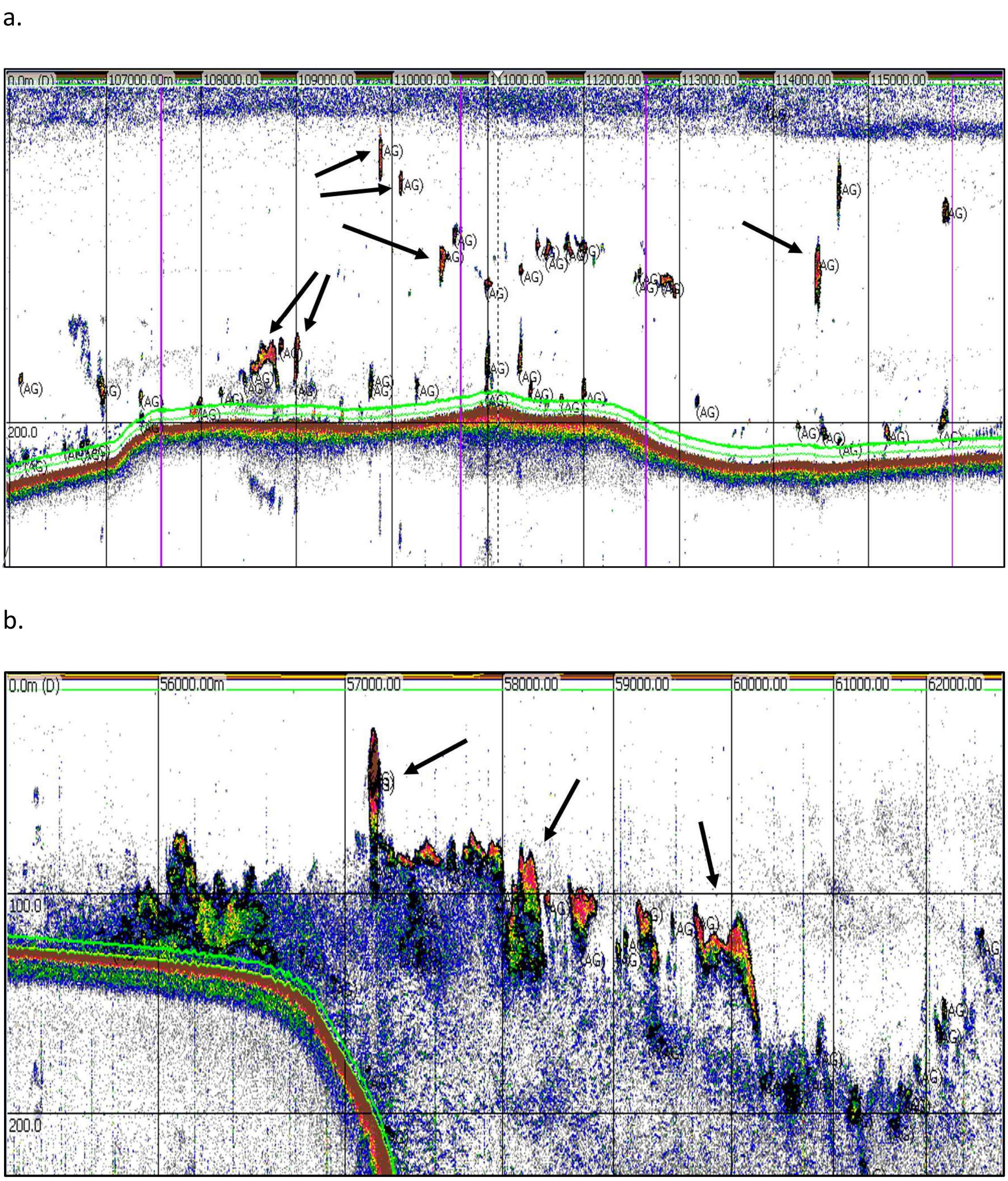

Figure 4. Sections of an echogram in raw volume backscatter data showing acoustic fish schools defined as strong scattering features that display discrete and continuous edges. The top echogram shows several small anchovy-like schools included throughout the water column from June 2008, and the bottom shows a large assemblage of schools near the shelf break from July 2006. The top of the echogram represents the surface of the ocean. The sea floor is the intense brown scattering feature at the bottom of the echogram and the upper green lines just above represent the 2 and 5 meter integration stop lines. Black arrows indicate anchovy-like schools as defined in the methods and that were included in the analysis.

Mean volume backscatter from the schools ranged from S_v -42.9 to -47.6 dB, with a S_v mean of -45.7 dB. Heights of schools varied between 1.2 and 36.2 m, with a mean of 9.3 m. The lengths of schools ranged from 4.2 to 2,074.1 m, with a mean of 125.2 m. Our acoustic descriptors of the 208 anchovy-like schools detected were larger, in deeper depths, and contained a slightly different S_v mean value than Lawson et al. (2001; Table S.2).

Anchovy-like Schools Detected During April and October
Regression ANOVA

Descriptor	N	Series	df	β	F	P <	Series	df	β	F	P <
School s_A nmi^{-1}	208	year	40	-64.0	5.61	0.023	month	40	-	0.12	0.74
School Depth	208	year	40	-	0.11	0.74	month	40	-	0.02	0.89
Bottom Depth	208	year	40	-	1.96	0.17	month	40	-	0.27	0.61

Anchovy-like Schools Detected During April and July
Regression ANOVA

Descriptor	N	Series	df	β	F	P <	Series	df	β	F	P <
School s_A nmi^{-1}	156	year	27	-65.1	4.20	0.051	month	27	-	0.08	0.78

Table 2. The top half of the table shows anchovy-like acoustic descriptors, number of schools detected between April and October, and regression ANOVA results showing a significant difference between years for s_A nmi^{-1}, but not for month. There were no significant differences between mean school depth, and bottom depth for both years and months. The bottom half of the table shows anchovy-like s_A nmi^{-1}, number of schools detected between April and July, and regression ANOVA results showing significant differences in s_A nmi^{-1} between years, but not months.

There were significant differences in s_A between years, but not months (Table 2). Schools detected in 2006 covered a total area of 720,617 m^2 nmi^{-2} with an average of 1,163 m^{2}nmi^{-1} being detected along transects, while anchovy-like schools detected in 2010 and 2015 represented the lowest total spatial coverage of the time series (Figure 5 and S.3). The number of schools detected nmi^{-1} in the months of May, June, July, September, and October was 0.04, 0.07, 0.03, 0.02, and 0.12, respectively. On average, anchovy-like s_A was greatest during the month of October, with an average of 1,274 m^2 nmi^{-1} detected along transects. However, October was only surveyed between 2004 and 2006. Surveys during September resulted the lowest average of anchovy-like coverage, with s_A 224 m^2 nmi^{-1} detected along transects.

There were no significant differences in school depth between years and there was no difference in associated bottom depths between years (Table 2). Anchovy-like schools were detected between 8.1 to 183.9 m depth, with a mean of 67.3 m and had associated bottom depths ranging between 16.4 to 637.8 m depth, with a mean of 156 m (Figure 6). Of the 208 anchovy-like schools detected, 37, or 17% were detected in offshore environments (mean bottom depth >200 m).

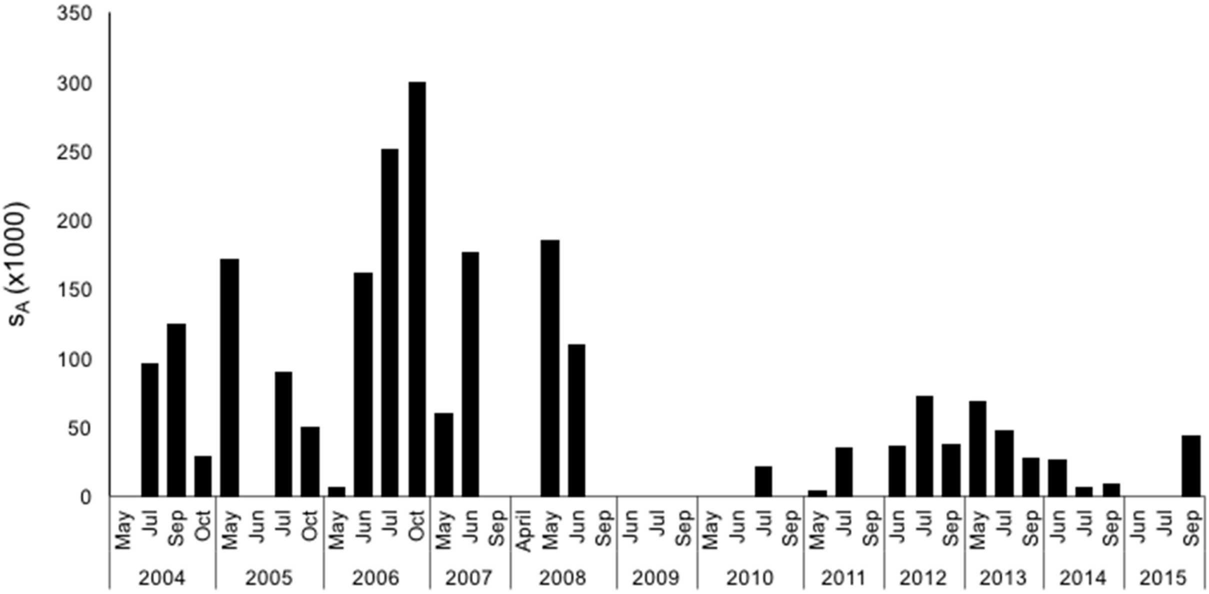

Figure 5. Represents total s_A of anchovy-like schools by year and month (n = 208).

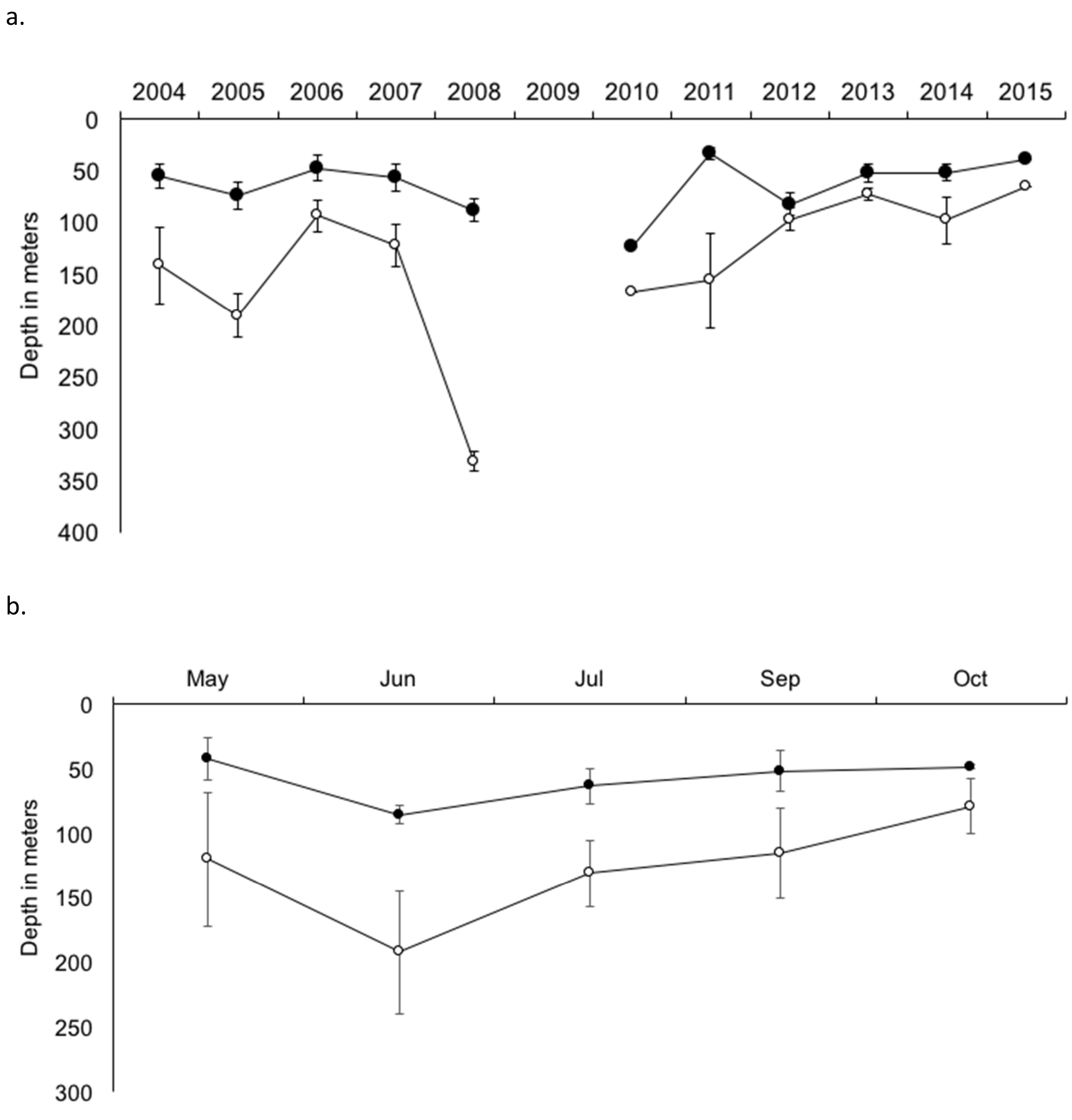

Figure 6. Mean depth (± SE) of acoustically identified anchovy-like schools (black circles) and associated mean bottom depth (white circles) by year (a) and month (b).

A total of 156 anchovy-like schools were detected between April and July (April was only sampled in 2008) (Figures 3 and 5). However, during 2009 and 2015, anchovy-like schools were only detected in the months of October and September. There was a significant negative trend in anchovy-like mean s_A from 2004 ($\bar{x}$ = 304 m^2 nmi^{-1}) to 2015 ($\bar{x}$ = 0 m^2 nmi^{-1}), but not between months (Table 2, Figure 5).

3.3 Acoustically observed YOY rockfish targets

The single target detection process resulted in 72,730 single targets with a *TS* equal to that of YOY rockfish consumed by seabirds (Table S.1). Acoustically-observed single targets do not display distinguishing characteristics like those of fish schools, therefore target strength was the sole feature used to classify YOY rockfish-like targets (Figure S.2). There were significant differences in total number of YOY rockfish-like targets nmi^{-1} between years, but no significant differences between months (Table 3). The total number of YOY rockfish-like targets detected was lowest between May 2004 and May 2011 ($\bar{x}$ = 3 nmi $^{-1}$), and highest between July 2011 and September 2015 ($\bar{x}$ = 76 nmi $^{-1}$) (Figure 7 and S.4).

YOY Rockfish-like Targets Detected Between April and October Regression ANOVA

Descriptor	Series	N	df	β	F	P <
YOY rockfish-like targets nmi^{-1}	year	72,730	40	4.39	31.59	0.00
	month	72,730	40	-	3.20	0.08

YOY Rockfish-like Targets Detected Between April and July Regression ANOVA

Descriptor	Series	N	df	β	F	P <
YOY rockfish-like targets nmi^{-1}	year	35,887	27	2.68	38.2	0.00
	month	35,887	27	5.12	4.59	0.04

Table 3. The top half shows the number of YOY rockfish-like single targets detected between April and October, and regression ANOVA results showing that there were significant differences in the number of single targets detected between years, but not months. The bottom half shows the number of YOY rockfish-like single targets detected between April and July, and regression ANOVA results showing that there were significant differences in the number of single targets detected between years and months.

Approximately 77% of the YOY rockfish targets occurred in the 35 to 45m depth layer, with the remaining 23% dispersed down from 45 to 300 m depth (Figure S.1). For the purpose of the analysis between the seabird diets and acoustic YOY rockfish indices, we used the YOY rockfish-like targets detected between April and July and were detected in the 5 - 45 m depth layer which included 50% of the total targets identified. This approach was taken because of the seabirds diving capabilities and inability to sample deeper depths effectively.

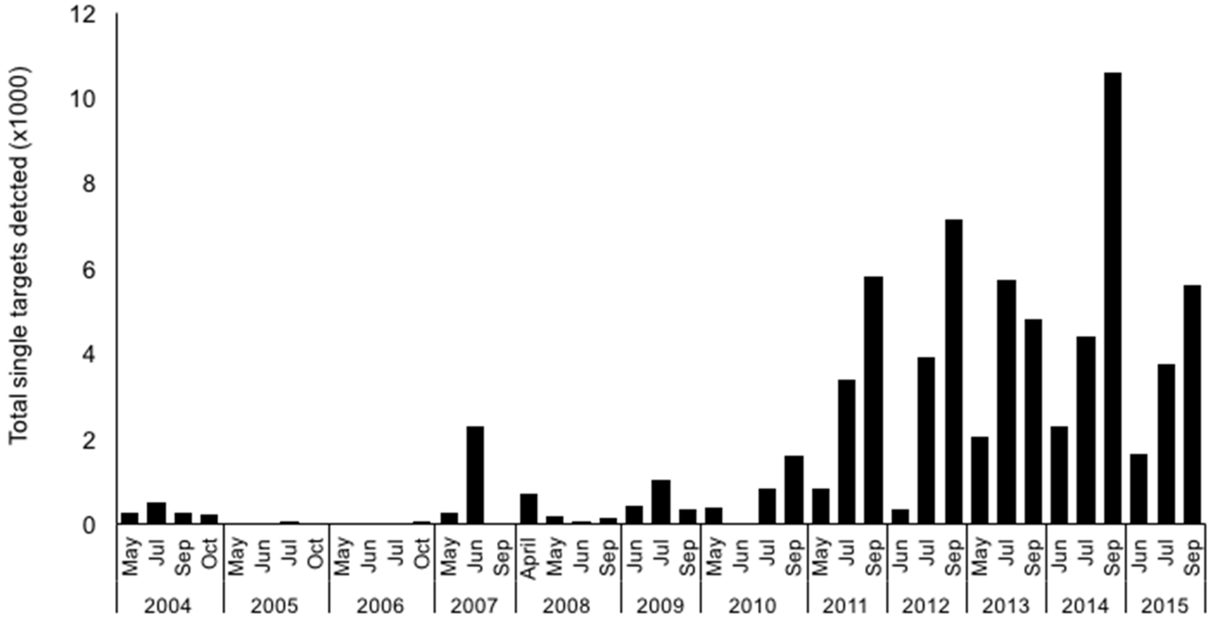

Figure 7. Represents total number of YOY rockfish-like single targets detected by year and month, not restricted by depth (n = 72,730).

From the 72,730 single targets, 35,887 targets were detected between April and July. We found a significant positive trend in the total number of detected YOY rockfish-like targets from 2004 to 2015 and between years and months (Table 3). The years 2005 and 2006 represented the lowest observed targets, with only 0.97 and 0.38 targets nmi^{-1} being detected. Rockfish targets were observed most frequently during 2013 - 2015, with 36, 41, and 93 targets nmi^{-1} detected on average, respectively (Figure 7 and S.4).

3.4 Evaluation of acoustic fish estimates

The standardized anomalies for anchovy-like s_A (hereafter, acoustic anchovy indices) were significantly positively correlated with the standardized anchovy indices estimated by the mid-water trawl survey (Table 4, Figure 8). Standardized anomalies representing the total number of detected YOY rockfish-like targets (hereafter, acoustic YOY rockfish indices) were significantly and positively correlated with the YOY rockfish indices estimated from the mid-water trawl survey (Table 4, Figure 8). Regarding seabird diet, the acoustic anchovy indices were significantly and positively correlated with the anomalies of anchovy consumed by all three seabirds (Table 4, Figure 9). The acoustic YOY rockfish indices, based on targets detected between 5 to 45 m depth, were significantly positively correlated with anomalies of YOY rockfish consumed by common murre (Table 4, Figure 9). Although positively and strongly correlated throughout the 5 to 45 m depth layer, YOY rockfish indices in the 5 to 15 m depth layer were more strongly correlated to the anomalies of YOY rockfish consumed by rhinoceros auklet, and by Brandt's cormorant (Table 4).

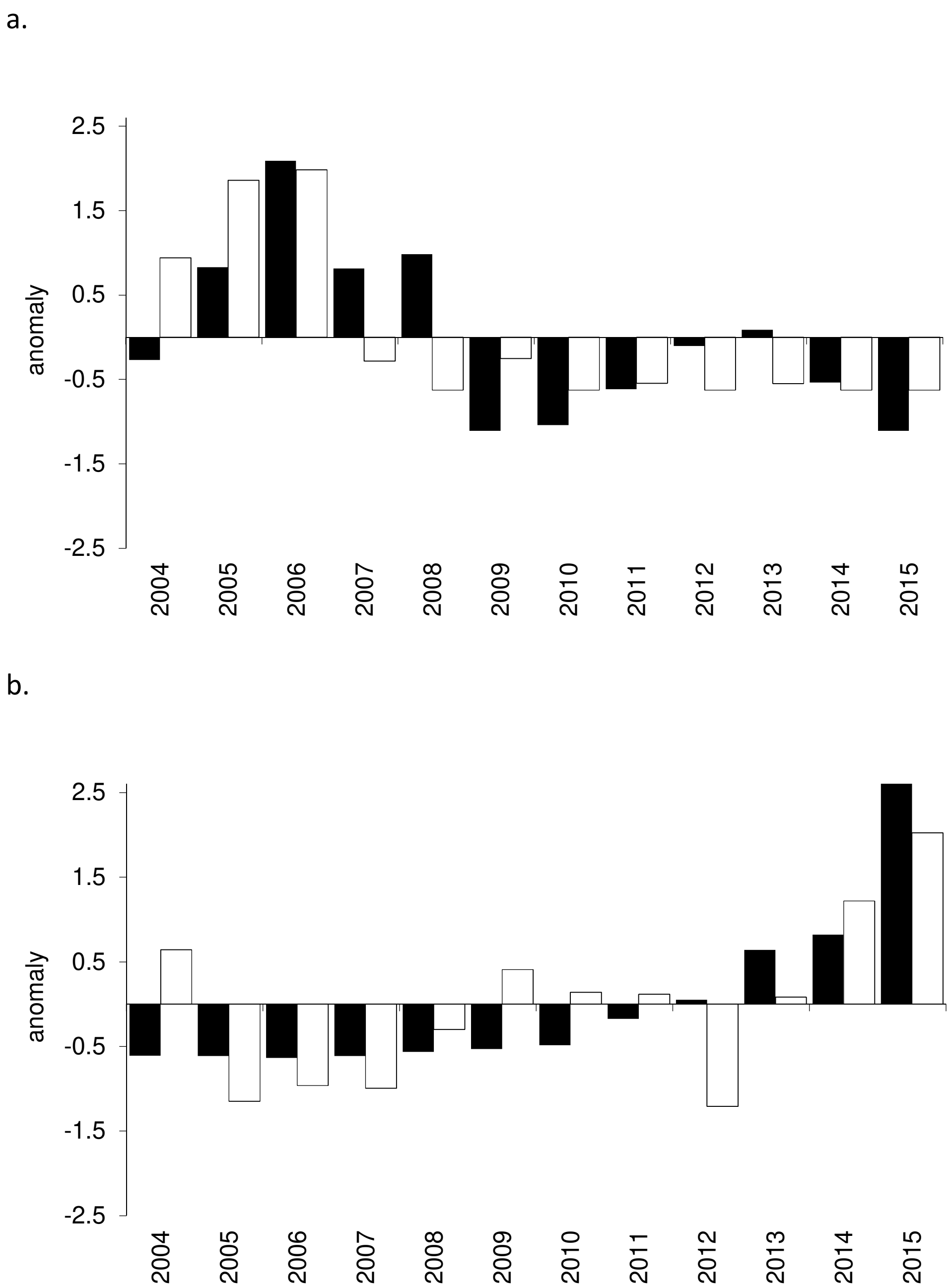

Figure 8. Graph (a) represents the standardized anomalies of anchovy abundance metrics indicated by s_A nmi^{-1} values calculated in this study (black bars) and NOAA-NMFS rockfish cruise assessments in the core survey region (white bars). The two independent series were correlated at $r = 0.63$ ($n = 12$). Graph (b) represents standardized anomalies of YOY rockfish abundance metrics indicated by total single targets detected nmi^{-1} throughout the water column (black bars) and NOAA-NMFS rockfish cruise assessments in the core survey region (white bars). The two independent datasets were correlated at $r = 0.72$ ($n = 12$).

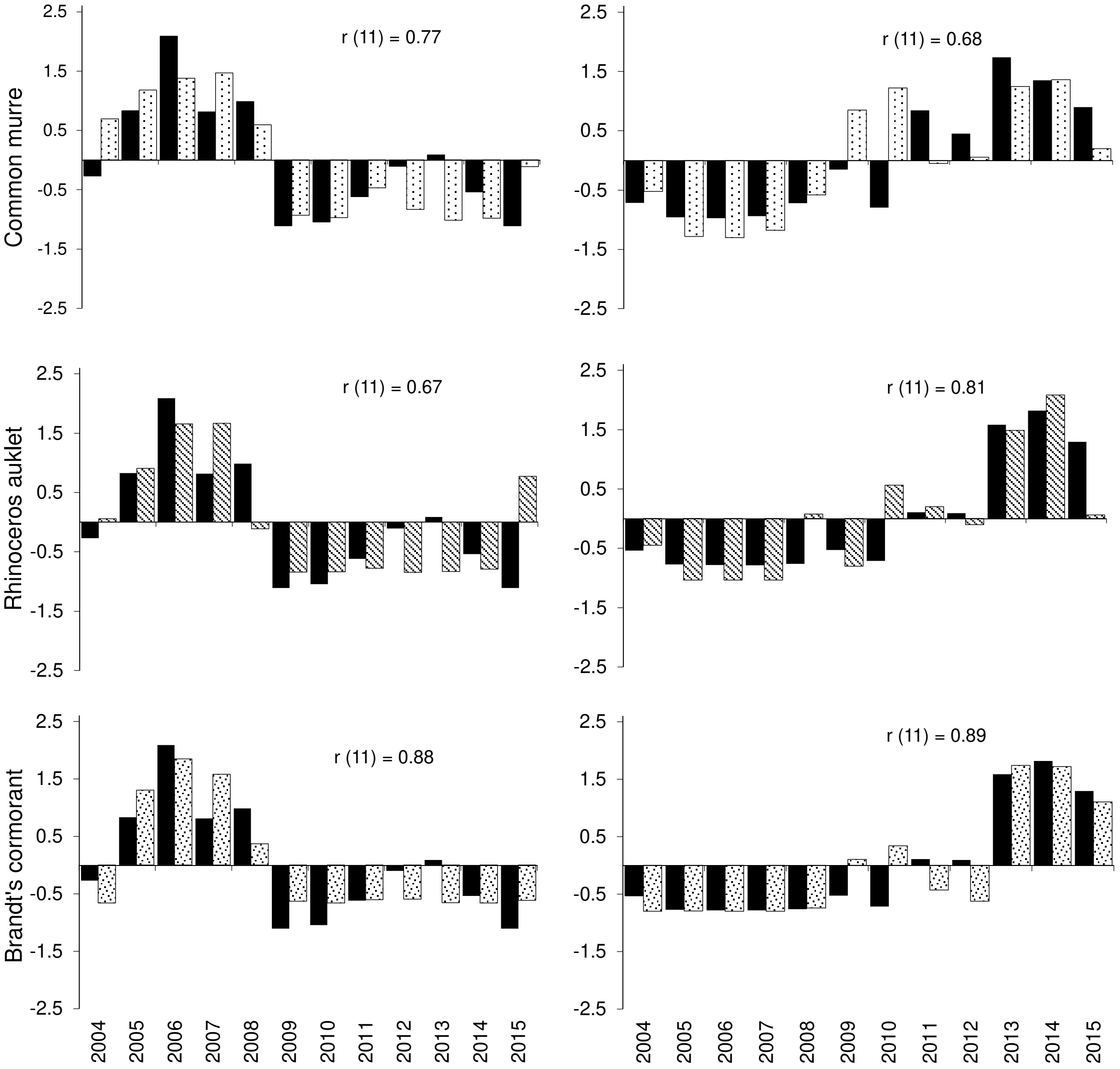

Figure 9. Standardized anomalies of anchovy-like s_A nmi^{-1} (left side, black bars) and YOY rockfish-like single targets nmi^{-1} (right side, black bars). YOY rockfish-like single targets for common murre were restricted to 5-45 m depth, for rhinoceros auklet and Brandt's cormorant targets were restricted to 5-15 m depth. Standardized anomalies of anchovy and YOY rockfish consumed by each bird species are represented by pattern filled bars.

Indices Comparison	Pearson Correlation		Regression ANOVA			
	r	P	df	F	R^2	P <
Anchovy/NOAA-NMFS	0.63	0.05	11	6.51	0.39	0.03
YOY rockfish/NOAA-NMFS	0.72	0.01	11	10.95	0.52	0.03
Anchovy/Common murre	0.77	0.01	11	14.25	0.59	0.004
Anchovy/Rhinoceros auklet	0.67	0.05	11	7.92	0.44	0.02
Anchovy/Brandt's cormorant	0.87	0.01	11	31.54	0.76	0.000
YOY rockfish/Common murre	0.68	0.05	11	8.51	0.46	0.02
YOY rockfish/Rhinoceros auklet	0.81	0.01	11	18.57	0.65	0.002
YOY rockfish/Brandt's cormorant	0.89	0.001	10	37.72	0.79	0.000

Table 4. Pearson correlation results and the Regression ANOVA results showing that the acoustic abundance indices for anchovy-like schools and YOY rockfish-like single targets are both significantly correlated and able to explain the variability observed in the NOAA-NMFS trawling data and in the diet of all three seabirds.

4. Discussion

Acoustically-derived abundance estimates are frequently used to assess population trends, distribution, and classify habitat associations of zooplankton and forage fish in marine ecosystems. However, verification data is often difficult and expensive to acquire, and may result in large uncertainties of abundance estimates (MacLennan & Simmonds 2013). In our study, the availability of long-term seabird diet observations and mid-water trawl surveys, demonstrate that acoustics display a marked coherence with these independent estimates of relative forage fish abundance. There are three main points of our study: 1) acoustic classification methods resulted in forage fish indices that relate to variability of seabird diet, 2) although slightly weaker, the acoustic abundance indices for anchovy and YOY rockfish are correlated with mid-water trawl estimates, and 3) using prey size from the seabird diet to calculate a *TS* range for YOY rockfish single targets is a viable method for developing population indices and tracking the relative abundance of this critical life stage of rockfish.

Concurrent net sampling to aid in classification of fish in acoustic data is common practice for fisheries management and science. The vessels used in ACCESS cruises lack the capability to gather net samples of fish, leaving a large acoustic data set without a direct way to classify or estimate forage fish abundance and distribution. To overcome this challenge, our study combined seabird diet and independent trawl surveys to evaluate their use in estimating temporal variability of forage fish occurrence. Acoustic classification of forage fish aggregations is difficult and errors may arise due to fish orientation, misidentification, and shifts in behaviour and distribution regionally (MacLennan 2013). Although our acoustic estimates are related to indices derived from the mid-water trawl survey, due to technique and design, the trawl survey may be missing patchily distributed forage fish aggregations, particularly at low population sizes. Additionally, midwater trawl surveys that are conducted at night, to reduce net avoidance, may miss an unknown percentage of the anchovy population that are dispersed at the surface. For example, between 2010 and 2016 only two tows, out of over 200 conducted, were positive for adult anchovies in this region, clearly indicating that the abundance was below the range of meaningful detection by trawl surveys alone. Similarly, in coast wide surveys to support stock assessments using the Acoustic Trawl Method, Zwolinski et al. (2012) had only 6, 4 and 1 positive tows for anchovies in 2006, 2008 and 2010, respectively (years of generally higher, albeit declining, anchovy abundance), further demonstrating the challenges of developing indicators of abundance from trawl data alone.

The high correlations between seabird-and acoustically-derived forage fish indices is likely attributable to sampling of the same forage fish populations due to overlap of the method in time and space. As central-place foragers, seabirds in our study select particular length-classes of forage fish surrounding their breeding colonies on the Farallon Islands, but can effectively sample prey populations due to species' different diet preferences, varying habitat preferences, and their ability to track patchy prey (Piatt et al. 2007). A primary caveat to using a *TS* calculated from seabird diet is the inability to capture the entire inter-seasonal variability of this life stage of rockfish. Although each sampling method is limited by spatial and temporal bounds, their high level of correlation shows that each can provide remarkable utility for describing the population trends of acoustically observed forage fish species.

4.1 Implications for anchovy variability

Anchovy tend to distribute in the water column forming densely packed schools during the day, and then vertically migrating and dispersing near the surface at dusk (Fréon et al. 1996; Kaltenberg and Benoit-Bird 2009). Acoustic-trawl surveys conducted between 1966 and 1973 in the study region indicated that anchovy schools were most commonly found between 9.2 and 73.2 m water depth (Mais 1974). Large sized schools were detected in the autumn of 1966 and 1967 between 164.6 to 182.9 m depth (Mais 1974). Previous studies found depth distribution to be critical for discriminating anchovy from other species, as their placement in the water column in relation to the seafloor (e.g. altitude index) was the most important descriptor (Lawson et al. 2001; Robotham et al. 2010). Of the 208 anchovy-like schools, 58% were detected between 8 and 73 m depth. The deepest school we detected was during September

2012 at 183.9 m depth and similar to previous observations made by Mais 1974, was considerably large with a height of 20.2 m and a length of 474.1 m. The depth distribution and increase in detection during October of anchovy-like schools is consistent with previous acoustic trawl surveys in the region (Mais 1974). However, in our study, discriminating based on the altitude of schools was not sufficient for classifying anchovy-like schools. This study required additional acoustic descriptors including schooling behavior and their associated energy backscatter (e.g. S_v) and morphological characteristics (e.g. visual cues). In addition to unique schooling behavior, anchovy display sensitivities to oceanographic conditions and tend to be more abundant off central California during weaker upwelling years (Chavez et al. 2003; Lindegren et al. 2013; Ralston et al. 2015; Elliott et al. 2016). In our study, the observed trends in the acoustic anchovy indices is indicative of a population following warm to cool ocean phases (e.g., 2004-2007) observed in the CCE (MacCall et al. 2016). Our findings on school depth distribution, associated bottom depths, energy characteristics, and population trends suggest that analysed schools fit the description of acoustically-observed anchovy schools (Mais 1974; Kaltenberg and Benoit-Bird 2009; Lawson et al. 2001; Robotham et al. 2010).

4.2 Implications for YOY rockfish variability

Adult rockfish in the CCE tend to form large aggregations in relation to high relief shelf breaks and slope habitats between 150 to 250 m depth, and have been described using acoustic methods (Chess et al. 1988; Demer et al. 2009; Keller et al. 2012). However, methods describing acoustic aggregations of the pelagic life stage of YOY rockfish are not yet available. YOY rockfish “habitat”, similar to anchovy, is best described in terms of depth distribution.

Using an earlier time series from the mid-water trawl survey, Lenarz et al. (1991) determined that 18 species of juvenile rockfish inhabited the water column at a depth range of 30.4 to 80 m with a mean depth of 56.7 m. However, Lenarz et al. (1991) found that catches of juvenile rockfish were relatively low when trawls were conducted at depths below 37 m. Using a time series from the mid-water trawl survey between 1987-1998, Ross and Larson (2003) found that out of 173,238 juvenile rockfishes caught, 169,406 were caught during 10 m and 30 m tows, with the remaining 3,832 being caught during 100 m tows. The acoustically-detected targets in our study were between depths of 5 to 275.3 m with a mean depth of 34.6 m, with 50% of targets being detected between 5-45 m (see results and Figure S.1). Depth distribution of the acoustically observed YOY rockfish-like targets suggests that the sampled targets are within the correct depth distribution range based on previous catch data, lending credence to the target strength range used to detect prey sized YOY rockfish (Moser and Ahlstrom 1978; and Lenarz et al. 1991; Ross and Larson, 2003). In addition to depth, peak abundances of acoustically observed YOY rockfish-like targets coincides with documented peak abundances of wintertime broods of YOY rockfish in the CCE (Ralston et al. 2013). In contrast to anchovy, YOY rockfish peak abundances occur during cooler ocean phases (e.g., 2008-2014) and tend to peak between April and July before settling into deeper habitats. Our findings on depth distribution and population trends of observed rockfish-like targets in the acoustic indices for YOY rockfish are reflective of findings observed in previous studies (Lenarz et al. 1991; Ross and Larson 2003; Ralston et al. 2013).

5. Conclusion

The correlation between the acoustic surveys and the mid-water trawl survey for Northern anchovy and YOY rockfish species is noteworthy, considering the incongruous spatial extents of the different surveys. However, both surveys were conducted annually within the central California Current and closely tracked a decade of marked ocean- climate variability, upwelling conditions, and marked changes in the abundance and distribution of krill and forage fish (Santora et al. 2014; Ralston et al. 2015). The coherence of local seabird diet with acoustically-derived forage fish availability also adds to findings from previous studies off central California, and confirms seabird diet as an exceptional indicator of food web structure and ecosystem (Ainley et al. 1993; Mills et al. 2007; Elliott et al. 2015, 2016). Further, by combining acoustics, seabird diets, and trawl surveys, our approach is likely useful for conducting ecosystem assessments in other upwelling ecosystems to better understand the spatial scales at which top marine predators and forage fish interact (Piatt et al. 2007; Bertrand et al. 2008; Tremblay et al. 2009). Additional research into habitat associations of anchovy and YOY rockfish acoustic indices could benefit the assessment of top predator foraging behavior (e.g., habitat energy budgets) and may provide insight on species interactions within trophic hotspots (Santora et al. 2017). For example, depths of forage fish species in particular play a crucial role in the energetic demand placed on diving seabirds such as the common murre and Brandt’s cormorant (Warzybok et al. 2018). Vertical distribution patterns of fish schools may be informative for designing forage fish habitat models specified with depth-specific ocean conditions

The acoustic characterization of anchovy-like school depth distribution and morphometric characteristics described in this study could benefit habitat forecasting models that aim to further describe habitat associations (MaCall et al. 2016; Schroeder et al. 2014). Associated bottom depths of anchovy-like schools described in this study provides some insight on anchovy concentrations nearshore (< 50 m bottom depth) that are under-sampled during current surveys (MaCall et al. 2016; Davison et al. 2017). Few anchovy-like schools were identified nearshore (<50 m bottom depth) in 2006, and provided little contribution to the estimated population size. This may suggest that if schools are missed, the relatively few schools inhabiting the nearshore environment adds little to the total population size (Davison et al. 2017). Research into how the two forage fish species distribute in relation to oceanographic conditions may provide further information on what environmental mechanisms are involved in the distribution of the two species. For example, exploring the effects of temperature, salinity, strength of stratification, and depth of upwelling on the distribution of both anchovy and YOY rockfish could provide a more complete overview of habitat requirements (Santora et al. 2014; Schroeder et al. 2014). Lastly, improvement in fish identification in acoustic data may be enhanced by incorporating numerical outputs into machine learning techniques (Robothom et al. 2010). Continued work in the realm of acoustic classification of fish species, fish behaviour, and predator prey relationships in the region will further our understanding of marine food webs and help make informed management decisions concerning marine environments.

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