Data summary and review of the PHMA hard bottom longline survey in British Columbia after the first 10 years (2006-2016)

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ABSTRACT

Doherty, B., Benson, A.J., Cox, S.P. 2019. Data summary and review of the PHMA hard bottom longline survey in British Columbia after the first 10 years (2006-2016). Can. Tech. Rep. Fish. Aquat. Sci. 3276: ix + 75 p.

The Pacific Halibut Management Association of BC (PHMA) longline survey was initiated in 2006 to improve information for stock assessment of data-limited inshore rockfish species in the 'outside' management unit of British Columbia. The PHMA survey was initially designed to provide indices of abundance for Yelloweye Rockfish (*Sebastes ruberrimus*) and Quillback Rockfish (*Sebastes maliger*); however, in recent years has been used in other groundfish assessments and for monitoring the Yelloweye rebuilding plan. Due to the growing interest in the PHMA survey, it is important to establish performance criteria for the original survey objectives and emerging uses. This report is divided into 2 parts: (1) a data reporting section that includes a summary of survey objectives, design, and trends in survey indices for 2006-2016, and (2) a review of the survey performance (i.e., sampling frame, stratification, sampling allocation, power analysis, survey precision) for Yelloweye and Quillback rockfishes. We evaluated spatial and depth-based differences in CPUE to identify 4 new stratification options that use combinations of 1-4 areal strata and the 3 current depth strata (20-70 m, 71-150 m, 151-260 m). We found mean annual CVs for northern and southern survey areas ranging from 8-11% for Quillback and 10-12% for Yelloweye under different stratifications. Power analyses indicate the PHMA survey has a low probability of detecting and correctly estimating the 13% population increase over 15 years that is targeted under the current Yelloweye rebuilding plan. The ability of the survey to detect population changes improves with increased tolerance for false positives (e.g. alpha > 0.1), larger population changes (e.g. +/- 25%), and longer monitoring time frames (e.g. 15-20 years). Mean CVs were also calculated for other rockfish species commonly encountered on the survey; Canary, Silvergrey, and Rosethorn all had mean CVs of 20% or lower, while Greenstriped, Redbanded, China, Tiger, and Copper rockfishes all had mean CVs of 30% or lower. Recommendations for improving the survey for Yelloweye and Quillback stock assessment include: 1) adopting a standardized protocol for generating PHMA survey indices (high priority); 2) using a 4 Area/3 Depth stratification in the North and South survey areas (high priority); 3) allocating sets in proportion to the number of survey blocks in each area-depth stratum, with a minimum of 3 sets allocated to each stratum (high priority); and 4) identifying the proportion of Yelloweye and Quillback habitat that is included in each survey stratum (low priority). Other considerations are outlined for multi-species survey applications, for which there is a need to clarify survey objectives and management needs.

RÉSUMÉ

Doherty, B., Benson, A.J., Cox, S.P. 2019. Résumé des données et examen du relevé à la palangre sur fond dur de la PHMA en Colombie-Britannique après les 10 premières années (2006-2016). Can. Tech. Rep. Fish. Aquat. Sci. 3276: ix + 75 p.

Le relevé à la palangre de l'association de gestion du flétan du Pacifique (PHMA) de la Colombie-Britannique a commencé en 2006 afin d'améliorer l'information disponible aux fins de l'évaluation des stocks d'espèces de sébaste côtier considérées comme ayant peu de données disponibles, dans l'unité de gestion « extérieure » de Colombie-Britannique. Le relevé de la PHMA a été initialement conçu pour fournir des indices d'abondance du sébaste aux yeux jaunes (*Sebastes ruberrimus*) et du sébaste à dos épineux (*Sebastes maliger*); au cours des dernières années, il a toutefois été utilisé dans d'autres évaluations des stocks de poisson de fond et pour la surveillance du plan de rétablissement du sébaste aux yeux jaunes. En raison de l'intérêt croissant pour le relevé de la PHMA, il est important d'établir des critères de rendement pour les objectifs initiaux du relevé et les nouvelles utilisations. Ce rapport est divisé en deux parties : (1) une section de communication des données qui comprend un résumé des objectifs, de la conception et des tendances des indices du relevé pour 2006-2016, et (2) un examen du rendement du relevé (cadre d'échantillonnage, stratification, répartition de l'échantillonnage, analyse de puissance, précision du relevé) pour les sébastes aux yeux jaunes et à dos épineux. Nous avons évalué les différences spatiales et de profondeur en CPUE pour identifier 4 nouvelles options de stratification qui utilisent des combinaisons de 1 à 4 strates surfaciques et les 3 strates de profondeur actuelles (20-70 m, 71-150 m, 151-260 m). Nous avons constaté que les CV annuels moyens des zones de relevé du nord et du sud étaient de 8-11 % pour le sébaste à dos épineux et 10-12 % pour le sébaste aux yeux jaunes sous différentes stratifications. Les analyses de puissance indiquent que le relevé de la PHMA a une faible probabilité de détecter et estimer correctement l'augmentation de 13 % de la population sur 15 ans qui est visée dans le cadre du plan actuel de rétablissement du sébaste aux yeux jaunes. La capacité du relevé à détecter les changements dans l'abondance de la population s'améliore avec une tolérance accrue aux faux positifs (p. ex. alpha > 0,1), aux changements plus importants dans la population (p. ex. +/- 25 %) et aux périodes de surveillance plus longues (p. ex. 15-20 ans). Les CV moyens ont également été calculés pour d'autres espèces de sébastes couramment rencontrées dans le relevé; le sébaste canari, le sébaste argenté et le sébaste rosacé avaient tous des CV moyens de 20 % ou moins, tandis que les sébastes à bandes vertes, à bandes rouges, à bandes jaunes, le sébaste tigre et le sébaste cuivré avaient tous des CV moyens de 30 % ou moins. Les recommandations pour améliorer le relevé d'évaluation des stocks de sébastes aux yeux jaunes et à dos épineux comprennent, entre autres: 1) adopter un protocole normalisé pour la génération d'indices de relevé de la PHMA (haute priorité); 2) utiliser une stratification à 4 zones/3 profondeurs dans les zones de relevé du nord et du sud (haute priorité); 3) répartir les ensembles proportionnellement au nombre de secteurs de levé dans chaque strate de profondeur de zone, avec un minimum de 3 ensembles alloués à chaque strate (haute priorité); et 4) déterminer la proportion de la population du sébaste aux yeux jaunes et du sébaste à dos épineux qui est incluse dans chaque strate du relevé (faible priorité). D'autres considérations sont décrites pour les applications de relevés plurispécifiques, pour lesquels il est nécessaire de clarifier les objectifs des relevés et les besoins de gestion.

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INTRODUCTION

The Pacific Halibut Management Association of BC (PHMA) longline survey was initiated in 2006 to improve information for stock assessment of data-limited inshore rockfish species occurring on hard bottom substrates in British Columbia. The survey covers waters in the 'outside' management unit of BC in areas on the West Coast of Vancouver Island and Northern BC at depths from 20-260 m (Fig.1.1). Approximately half of the total survey area is surveyed each year with sampling alternating between the northern and southern survey areas every year.

This report is divided into 2 parts: (1) a data reporting section, including a summary of survey objectives, design, and trends in survey indices for 2006-2016 and (2) a review of the survey performance for the key species in the survey (Yelloweye and Quillback rockfishes), as well as recommendations for improving the survey.

PART 1 – SURVEY DOCUMENTATION & DATA REPORTING

1.1. PHMA SURVEY OBJECTIVES AND SPECIES OF INTEREST

The PHMA survey was initially designed to sample areas with hard bottom substrate in untrawlable habitats for Yelloweye Rockfish (*Sebastes ruberrimus*) and Quillback Rockfish (*Sebastes maliger*) (Yamanaka and Logan 2010). Survey indices are intended to provide relative abundance indices and provide biological samples for Yelloweye and Quillback rockfishes as well as other rockfish species commonly encountered on the survey (Table 1.1), including inshore rockfish species (e.g. China, Copper, Tiger) that are not well indexed by the DFO synoptic bottom trawl surveys. The survey data are also used for non-rockfish assessments. To date, the PHMA survey data have been used in assessments for Skate, Quillback Rockfish and Yelloweye Rockfish (DFO 2012; DFO 2014a; Yamanaka et al. 2018). In this report, we focus on evaluating the performance of the PHMA survey for the key rockfish species encountered on the survey.

Survey accuracy, precision and cost are all important for evaluating survey performance. Ideally, fisheries surveys should aim to minimize costs while providing indices of relative abundance that are both accurate (e.g. representative of the stock) and precise enough (i.e. low uncertainty) to produce assessment outputs that can provide useful information for the management needs of the fishery. To reduce bias and provide indices that are representative of overall population trends, best practices for fisheries-independent surveys generally aim for: (1) standardized survey protocols (e.g. gear type, bait, soak time) that are consistent from year to year, (2) a survey sampling area that is representative of the entire population of interest and (3) randomized sampling throughout the identified habitat range rather than focusing on areas of high abundance (Derisio et al. 1998; Kimura and Sommerton 2006; Rotherham et al. 2007). There is usually a trade-off between cost and survey precision since increasing survey precision often involves more sampling that can be prohibitively expensive; however, the precision of survey abundance indices can also be improved by modifying survey stratification or sampling allocation without increases to overall sampling effort (Smith and Gavaris 1993). Survey precision is typically measured as the sampling variance in annual estimates of survey CPUE and can be expressed as the coefficient of variation (CV), calculated as the standard error of mean CPUE divided by mean CPUE (Hatch et al. 2002; Stanley et al. 2007; Smith et al. 2011). There are no universally accepted standards for fisheries survey precision since the target survey precision for a stock will depend on stock assessment methods and the population trends that must be detected for management. Statistical power analyses for trend detection or simulation trials can evaluate survey performance for different ranges of CVs and can be used to inform the selection of appropriate target CVs (See Part 2 of this report). In practice, the range of target CVs varies widely among fisheries. For example, a target CV of 5% was used for evaluating sampling design and stratification options for Pink Shrimp trawl surveys in Biscayne Bay, Florida (Ault et al. 1999), while a CV of <20% has been proposed as an initial target for some Canadian fisheries surveys such as groundfish trawl surveys in BC (Sinclair et al. 2003) and the recently re-designed Atlantic Halibut longline survey (Cox et al. 2018). Target precision in the groundfish trawl survey was later refined to CVs <40% for up to 34 stocks that accounted for 80% of catches on the survey (Stanley et al. 2004). Stanley et al. (2004) suggested rankings for different ranges of CVs according to their ability to track population changes as: excellent (<20% CV), good (20-30% CV), adequate (30-40% CV), poor (40-60% CV), and very poor (60% CV).

Target levels of survey precision (e.g. CV) have not been identified for the different species captured in the PHMA survey. Similarly, the level of population change that the survey aims to detect and the time horizon for detecting population trends has not been specified. DFO has periodically conducted simulations to assess the ability of the PHMA survey to detect population changes over time for sample sizes between 100 and 400 sets per year with annual, biennial, or triennial surveys (see methods in Stanley et al. 2007). The March 2016 DFO-PHMA survey study (Attachment C in DFO-PHMA 2016) indicated a high degree of uncertainty in the ability of the survey to reliably estimate population trends. The study used simulations to determine the probability of detecting a 50% increase or a 25% decline over 20 years for Quillback, Yelloweye, and Copper rockfish populations in the northern and southern survey areas based on 200 sets in each area every 2 years (e.g. 10 northern surveys and 10 southern surveys over 20 years). When the true population trend was an increase of 50% over 20 years, estimated trends from the simulated survey data ranged from declines of 50-75% to increases of 275-350% depending on the species and area. Similarly, when the true trend was a population decline of 25% over 20 years, trend estimates ranged from increases of 90-110% to declines of 70-80%, depending on the species and area. There was a high frequency of simulations with estimated population trends that were not within 100% of the true population trend. For example, when the true population trend was a 25% decline, 21-26% of Yelloweye and Quillback simulations had either a population increase or a decline of 50% or more (i.e. 2 times worse than the actual decline). Imprecise estimation of population trends could have severe consequences for the fishery. For instance, a false positive increasing trend could lead to overharvesting in the near term and potential conservation concerns in the future, while a false positive declining trend would likely trigger reductions in TACs and potential closures in some areas. Therefore, it is important to design surveys that can detect population trends within a timeframe and tolerable range of uncertainty required for management decisions. These results emphasize the need to evaluate survey performance and frame management decisions and timelines accordingly, so that progress towards conservation objectives can be reliably measured.

1.2. SURVEY STRATIFICATION AND SAMPLE ALLOCATION

The PHMA survey is a stratified random design with 3 depth strata: shallow (20-70 m), medium (71-150 m) and deep (151-260 m), with 2 km x 2 km grid cells selected to include Yelloweye and Quillback hard-bottom habitat in untrawlable areas for the BC ‘outside’ population (Fig. 1.2-1.3). Each grid cell is assigned a depth stratum based on the average grid cell depth. The lower and upper bounds of depth strata represent the 5th and 95th percentiles of depths where Yelloweye and Quillback are captured. Depth strata were selected during the initial survey design to minimize the variance in catch rates from commercial logbook and research survey data among different depth intervals (Pers. Comm., K. Cooke, DFO). All grid cells in the 20-260 m depth range that included historical commercial hook and line catch records for Yelloweye and Quillback were initially considered for inclusion in the survey (Yamanaka and Logan 2010). The survey grounds were refined following consultation with the commercial longline industry (Pacific Halibut, Rockfish, and Spiny Dogfish fisheries) to remove grid cells that fishermen identified as soft-bottom or 'dead grounds' without rockfish habitat. Grid blocks were also removed from the survey if there was a 50% overlap with Rockfish Conservation Areas (RCAs) or Sponge reef area closures (Pers. Comm., Lynne Yamanaka, DFO). The initial survey design in 2006 had 6 197 blocks, however; grid cells have been removed over time due to incorrect depth stratification or areas deemed unfishable (Pers. Comm. K. Cooke, DFO). In 2010, the PHMA survey grid was aligned with the trawl survey grid and some overlapping PHMA blocks were removed. Select survey blocks were also removed due to proximity with First Nation communities and from isolated areas with few fishable blocks (Pers. Comm. L. Yamanaka, DFO). The most recent survey sampling frame contains 3 105 blocks in the north and 2 849 blocks in the south, for a total of 5 954 unique blocks (Table 1.2).

Statistical power analyses based on commercial and research survey catch rates for Quillback and Yelloweye collected in 1997-1998 and 2002-2003 were used to determine sample sizes for the survey. There were initially 190 survey blocks targeted for annual sampling, along with 10 additional samples added to account for unfishable blocks, for a total of 200 sets per year (Pers. Comm., K. Cooke, DFO). There were between 186-197 longline survey sets deployed annually between 2006-2016 (Fig. 1.4-1.5), with the exception of 2013 when the survey did not occur. Sampling blocks are randomly selected without replacement in each year, with the number of sampling blocks allocated approximately in proportion to the number of available blocks in each depth strata by management area (e.g. 3C, 3D, 4B, 5A, 5B, 5C, 5D, 5E). The northern survey area includes survey blocks in management areas 5E, 5D, 5C, and 5B in waters around Haida Gwaii, Dixon Entrance and Hecate Strait (Fig. 1.2). The southern survey area includes blocks in management areas 5B, 5A, 4B, 3D, and 3C in waters on the West Coast of Vancouver Island and Queen Charlotte Sound. Only a small portion of 4B is included in the sampling grid; there are 34 blocks in 4B that cover a small portion of PFMA 12 in northern Queen Charlotte Strait (Fig 1.3). The southeast corner of area 5C around Price Island is officially part of the Northern survey area but was surveyed during the southern survey years in 2007 and 2009 (Fig. 1.5). Otherwise, blocks in area 5C are only surveyed in northern survey years (Table 1.3).

1.3. SURVEY PROTOCOLS AND CATCH SAMPLING

The PHMA longline survey deploys standardized gear with a target of 450 14/0 circle hooks with 12-18 inch gangions and an overall gear length from snap to hook of 20-26 inches. Hooks are evenly spaced at 8-foot intervals along the groundline, resulting in total set lengths of approximately 3,600 feet (1.1 km). The first survey year in 2006 deployed sets with 500 hooks, after which hook numbers were reduced to 450 to accommodate 8-foot spacing along the groundline (Pers. Comm. L. Yamanaka, DFO). The bait used for survey sets is whole squid that is cut into 30 g pieces for baiting each hook. Sets are deployed for a soak time of 2 hours, measured from the time of the last anchor in the water during setting and the time of the first anchor out of the water during hauling. Survey sets are conducted during daylight hours with sets beginning ½ hour after sunrise and all gear out of the water ½ hour before sunset, which usually allows for up to 4 set locations to be completed per day. The vessel master may place a set anywhere within the 2 km x 2 km survey block, on hard bottom, as long as all hooks between the anchors land within a designated block at the specified depth stratum. Between 2010 and 2012, the search time for determining the set location within a block was standardized to 45 minutes (Pers. Comm. L. Yamanaka, DFO). A temperature/depth recorder is attached to the middle of the groundline for each set.

The selected survey blocks in each year are divided annually into three areas of similar size with approximately 66 sets each, with the exception of 2015 when all survey blocks were divided between two vessels. Commercial fishing vessels submit bids to conduct survey sets and biological sampling in one of the three areas (Table 1.4). The survey is conducted between August 1 and September 15, and all allowable commercial groundfish species that are landed from the survey are sold to help fund the survey. All rockfish catch must be retained as well as all legal/marketable sizes of Halibut, Sablefish and Lingcod. Dogfish, Big Skate and Longnose Skate, are also caught on the survey but are not retained.

The contents/condition of each hook on the set are recorded upon retrieval of the gear (e.g. species present, empty hook, missing/bent hook, or bait/skin still on hook). Biological sampling is conducted for rockfish species and occasionally for sharks. As of 2016, the priority species for biological sampling were: Yelloweye, Redbanded, Quillback, Copper, China, Tiger, and Black rockfish, listed in order of decreasing priority. Other rockfish species are sampled as time permits. Otoliths, sex, maturity, length, and weight are collected for all Yelloweye Rockfish on a set for up to 50 individual fish. If there are greater than 50 Yelloweye Rockfish caught on a set, a random subset of 50 Yelloweye Rockfish are sampled. If there are less than 50 Yelloweye Rockfish on a set, all Yelloweye are sampled first followed by other priority rockfish species until at least 50 fish are sampled. DNA samples are also collected for all Rougheye/Blackspotted Rockfish.

1.4. DATA PROCESSING

All CPUE indices were standardized to 450 hooks to account for differences in the number of hooks fished per set, which range from 349-514 hooks per set during 2006-2016 surveys. There were 30 sets out of 1 950 sets from 2006-2016 that were excluded from CPUE calculations as they occurred in areas that were closed to fishing or blocks that have since been removed from the survey grid. CPUE indices of counts/450 hooks are straightforward to calculate from PHMA longline survey catch data for northern and southern survey areas because the total number of rockfish species captured per set has been recorded for all survey years from 2006-2016. CPUE in kg/450 hooks requires conversion of rockfish counts to weights based on length measurements and mean weights in biological sampling data. This conversion is required for 2007-2016 only, as total weight by species and set was recorded in the first year of the survey.

Biological samples of either total catch or a random subset of individuals were collected for most sets with Yelloweye (1259 out of 1284 sets) and Quillback rockfish (937 out of 1013 sets). Sampling includes length, weights, sex, maturity, and/or otoliths from individual fish. Specimen weights were recorded in the biological data for 2009-2016 survey years. These are used to fit length-weight curves for Yelloweye and Quillback rockfishes (Fig. A.1, B.1) where $W = aL^b$ a and b parameters are estimated by fitting a linear regression to the log-transformed weight and length values. Fitted length-weight models are used to estimate weights for biological samples with length records only. Catch numbers for each set are converted to weights using the mean weight from the set. A small number of sets do not have any length or weight data for Yelloweye (23 sets with 245 total fish) or Quillback (62 sets with 1009 total fish). For these records, numbers are converted to weights using the mean weight by depth strata and year (Table 1.5).

Sets are assigned to a survey block and area-strata using the estimated set midpoint location and assuming a straight line between the start and end deployment locations (Fig. 1.4-1.5). Depth strata are assigned using the best available depth information for each set based on modal set depth (1736 sets), the average of the recorded start and end depths (133 sets), or the recorded depth at the beginning of the set (81 sets). This process results in 5% of sets (91 out of 1950 sets) being assigned to different depth strata than originally indicated in PHMA survey data provided by DFO, most of which were from 2006-2009 and may be related to the realignment of the PHMA survey grid that occurred in 2010 (Table 1.6).

1.5. TRENDS IN 2006-2016 PHMA HARD BOTTOM LONGLINE SURVEY DATA

Spatial and depth trends in CPUE for Yelloweye and Quillback rockfishes are shown on Figures A.2 and B.2, respectively. Yelloweye Rockfish exhibit large spatial differences in CPUE, with highest CPUE for survey areas in 5E, 5B, 5A4B and 3D (i.e., West Coast of Haida Gwaii, Queen Charlotte Sound and Strait, and the Northwest Coast of Vancouver Island) (Fig. A.2). Yelloweye CPUE is lowest in areas 5D, 5C, and 3C. Yelloweye also exhibit a relationship with depth, with increasing CPUE with depths up to approximately 200 m (Fig. A.2). Quillback CPUE is less variable across management areas (Fig. B.2), but is on average higher in the north (5E, 5D, 5C and 5B), than in the south (5A4B, 3D, 3C). Quillback CPUE is similar in shallow and medium strata, but very low at depths deeper than 150 m. Only 24 out of 529 sets in the deep strata (150-260 m) caught any Quillback; only 3 of these were at depths > 200 m.

There is a positive correlation between depth and length for both Yelloweye (Pearson's ρ=0.22, p<0.001) and Quillback (Pearson's ρ=0.26, p<0.001), with larger individuals on average being captured at deeper depths (Fig. A.3, B.3). Yelloweye and Quillback caught on the survey range from 5-121 and 7-84 years old, respectively (Figs. A.4-A.7, B.4-B.7). For 2006-2012 surveys, the average age of Yelloweye Rockfish in each year ranges from 32-34 years in the North and 31-33 years in the South. Both northern and southern age-distributions include older fish with higher proportions of fish >35 years in the North than in the South (Fig. A.6). Yelloweye age appears to have a slight positive correlation with depth (Pearson's ρ=0.11, p<0.001), with average ages of 28, 32, and 34 for Yelloweye sampled in shallow, medium and deep strata, respectively. The age-distribution for Yelloweye includes older fish within all three depth strata (Fig. A.7) and while there are no fish > 100 years old in the shallow depth stratum (20-70 m), this may be due to fewer age samples from the shallow stratum (1 487 samples) compared to the medium (5 852 samples) and deep stratum (4 729 samples). We found no strong correlation between age of Quillback rockfish and depth of capture (Pearson's ρ=-0.05, p=0.001). The age distribution for both the North and South are similar with the majority of ages in the 10-40 year range (Fig. B.5-B.6). Quillback Rockfish were older in the North on average, with means of 29 and 27 years old for the North and South, respectively, for 2006-2009 survey years (Fig. B.5). Both the shallow and medium depth strata in the 20-150 m depth range contain the full range of Quillback ages (Fig. B.7). The proportion of females in Yelloweye catches is slightly higher than males with an average of 54% females across all sets, ranging from 52-59% for different survey areas (Fig. A.8). For Quillback, there is a slightly smaller proportion of females in catches with an average of 46% females across all sets, ranging from 43-50% for different survey areas (Fig. B.8). The proportion of males and females in rockfish catches can change seasonally, with more females generally caught in the spring and more males in the fall (Pers. Comm., L. Yamanaka, DFO.)

PART 2 - REVIEW OF SURVEY DESIGN AND PERFORMANCE

2.1 INTRODUCTION

Genetic studies have identified discrete populations of Yelloweye for inside and outside management units but failed to find finer population structure of the outside Yelloweye Population (Yamanaka et al 2006a, Siegle et al. 2013). Genetic studies for Quillback did not find evidence of discrete populations in BC; however, the inshore and outside populations continue to be managed as separate stocks (Yamanaka et al. 2006b). Little is known about the spatial structure and connectivity of other inshore rockfish species in British Columbia. It is likely that some inshore species, such as Copper, Quillback, and Yelloweye rockfishes, have important spatial stock structure given their limited movement range (<3 km) and high site fidelity indicated from tagging studies (Coombs 1979; Mathews and Barker 1983; Stanley et al. 1994; Hannah and Rankin 2011). Larval dispersal rather than movement of adults is likely the main mechanism for connecting sub-populations in different areas over large geographic distances (Johansson et al. 2008). Many rockfish species also have a patchy distribution, possibly due to preferences for certain depth ranges or habitats (Johansson et al. 2008), which in combination with their limited movement makes them vulnerable to localized depletion (Hanselman et al. 2007). Localized depletion occurs when there is a reduced population over a small spatial area, which may affect productivity and recovery rates differently in those areas relative to the rest of the stock (Hanselman et al. 2007; Cianelli et al. 2013). It is therefore important that survey efforts for inshore rockfish cover enough of their habitat range to monitor localized changes in abundance and to provide representative abundance indices for management units of BC rockfish populations.

The distribution of historical commercial catch and the International Pacific Halibut Commission (IPHC) survey catch indicate that the PHMA survey grid may not cover the full extent of Yelloweye and Quillback habitat. If there is a mismatch between species habitat and the survey grid, then different proportions of habitat may be surveyed within different depth-management strata and weightings used to calculate stratified survey indices may over or under-represent population trends in some strata. Spatial differences in Yelloweye abundance varies substantially between management areas, with higher observed CPUE in Haida Gwaii (5E, 5B north) relative to the other management areas and very low catch rates in area 3C (Fig. A.2). Given that Yelloweye abundance is non-uniform throughout the different depth-management areas of the PHMA survey, it is important to carefully evaluate the weightings assigned to each stratum. We therefore evaluated the coverage of the PHMA survey sampling frame by comparing the PHMA survey grid with locations of historical commercial catch in BC groundfish fisheries and the IPHC fixed-station survey.

A major challenge with fisheries surveys is that variability in annual catch rates can make it difficult to separate 'noise' from the true trends occurring in a population over time (Gibbs et al. 1998). The sampling variance in annual survey indices (i.e. CV) will vary by fishery, and target levels of survey precision are difficult to identify without power analyses or other simulation work comparing survey or assessment outcomes with management needs (Gibbs et al. 1998). Statistical power analyses can be used to estimate the probability that a survey can detect different population trends for different CVs, the frequency of sampling and the timeframe over which the population trend will be estimated (Gerrodette 1987). Surveys should be regularly evaluated to ensure that survey outputs can provide adequate information for assessment. In cases where survey precision is not adequate to detect the population changes needed for management, adjustments to the survey design or increased sampling frequency may be used to improve performance. If the required changes are not feasible, the expectations for assessments and management procedures may need to be adjusted to better align them with the reality of the survey.

The ability of the PHMA survey to detect the population changes required under the current rebuilding plan for Yelloweye Rockfish has not been established. The rebuilding plan aims to: *“Achieve rebuilding throughout the outside stock’s range and grow out of the critical zone within 15 years, with a 57% probability of success”* (DFO 2015a). Based on the 2015 stock assessment for Yelloweye (DFO 2015b), an increase from the 2014 median biomass estimate of 3 821 t to the limit reference point of 0.4 B_{MSY} would reflect a 13% increase in the population size. The harvest strategies and assessment horizons for many other rockfish species in BC are not clearly defined; however, it is likely that the PHMA survey will provide critical inputs for their assessment plans in the future. Power analyses can provide useful information for determining multi-species target CVs and identifying appropriate management options.

We used survey precision and statistical power as the primary metrics to assess the PHMA survey performance for commonly encountered rockfish species. Survey CVs for rockfish species commonly encountered on the survey were calculated using alternative area stratification and sampling allocation options that may improve survey precision for Yelloweye and Quillback rockfishes. Statistical power analyses were used to estimate the probability of detecting 10, 25, and 50% changes in a population over 10-20 years based on CPUE indices for a range of different CVs. The survey precision and power analyses provide information on the ability of the survey to detect the targeted population increases proposed under the current Yelloweye rebuilding plan and can serve as a guide for identifying target levels of survey precision for other species.

2.2 METHODS

2.2.1 Evaluating survey sampling frame

We compared the PHMA survey grid with the distribution of historical catches by BC commercial fisheries and the IPHC longline survey to evaluate the extent to which Yelloweye and Quillback habitats are represented in the survey sampling frame. The comparison allows identification of any areas with historically high catches of Yelloweye or Quillback that are not currently surveyed, or alternatively areas with zero Yelloweye or Quillback catches that are included in the survey.

Spatial catch data from commercial longline hook and trap fisheries from 2006-2016 was obtained from DFO commercial groundfish data at a resolution of approximately 18 km x 18 km grid cells, excluding locations that did not have at least 3 vessels fishing in each year. We mapped grid cells of total commercial catch of Yelloweye and Quillback rockfishes and overlaid PHMA survey strata.

The IPHC longline survey uses a fixed-station design extending from Oregon to Alaska, which is used to provide abundance indices for Pacific Halibut (*Hippoglossus stenolepis)*. The survey is conducted annually in British Columbia waters (IPHC regulatory area 2B). The survey within BC waters has included 128 stations (1998, 2000) or 170 stations (1999, 2001-2016) that are equally spaced on a 10 nautical mile grid (Flemming 2012; Yamanaka et al. 2018). The IPHC survey grid covers most of the same areas as the PHMA survey strata, with the exception of the southwest coast of Haida Gwaii and shallower inshore areas. The Canadian IPHC stations were surveyed between 15 and 18 times from 1998-2016. For each station, we calculated mean Yelloweye CPUE (pieces/450 hooks) for surveyed years and identified the number of years with

Yelloweye Rockfish catch. We calculate IPHC CPUE as pieces per 450 hooks to generate CPUE indices on the same scale as the PHMA survey; however, there is currently no calibration method to allow direct comparison of CPUE from both surveys. The IPHC survey uses conventional fixed gear without swivels and larger 16/0 circle hooks instead of the 14/0 hooks and snap/swivel gear used on the PHMA survey. IPHC surveys have historically deployed 5-8 skates per station and the number of hooks where rockfish catch was recorded has varied from 50-800. Yelloweye catch is recorded for all hooks at each IPHC station in British Columbia with the exception of surveys conducted in 1998-2002 and 2013, so these years have a lower probability of observing at least 1 Yelloweye at a station (Flemming 2012; Yamanaka et al. 2018 - Appendix B).

2.2.2 Optimizing stratification and sampling allocation

The goal of stratification in the PHMA survey is to increase precision of survey abundance indices for Yelloweye and Quillback. This is achieved by dividing the outside population into multiple areas (i.e. strata) that have less variability in CPUE within each stratum than the variance of the whole population. The mean CPUE estimates of each stratum can then be combined into an estimate for the whole population that has less variability (Cochran 1977).

CPUE, age, sex, and length composition for Yelloweye and Quillback were examined by depth and area to assess potential depth or spatial effects that may inform improved stratification options (See Figures in Appendix A and B). The current survey is stratified by depth but not by area; however, area stratification may provide additional gains in survey precision (Smith and Gavaris 1993; Cox et al. 2018). The frequency distribution of the variable of interest (i.e. index of abundance), is the best measure to construct strata boundaries (Cochran 1977). Thus, annual normalized CPUE is used to select strata (Smith and Gavaris 1993). The normalized values are then binned into 6 stratum groups with approximately equal intervals based on the cumulative square root of the frequency distribution of CPUE (following methods described in Cochran 1977 p.128-131 and Smith and Gavaris 1993). Maps of the 6 normalized CPUE strata showed large spatial variability that would produce a patchy mosaic of blocks for each stratum if used to select area strata (Figs. 2.1-2.4). To rectify this, we selected geographical boundaries that contained the regions with the most similar CPUE that also aligned closely with management area boundaries (Smith and Gavaris 1993). Each area stratum contained areas with more similar catch rates for Yelloweye and Quillback than neighbouring strata. We identified 4 stratification options based on combinations of areal strata and the 3 current depth strata: 1A-3D (no area strata, 3 depth strata), 2A-3D (2 area strata, 3 depth strata), 3A-3D and 4A-3D (Figs. 2.5-2.6). The areas with the largest differences in catch rates were selected for the 2A-3D stratification, and were then further subdivided for the 3A-3D and 4A-3D stratification options. For example, sets in area 5E/5B in the North have much higher Yelloweye catch rates than in 5D/5C, with CPUE that is often 6.5-15.5 times the mean annual CPUE. These areas were assigned to separate strata. The 5E/5B and 5C/5D zones were separated into 2 area strata for the 2A-3D stratification in the North and then further subdivided by management areas for 3A-4D and 4A-4D. In the South, area 3C has very low Yelloweye CPUE in comparison to 3D/5A/5B and was the first area assigned to a separate stratum for the 2A-2D option. The inshore area of 5B has lower Yelloweye catch rates and was assigned a separate stratum for 3A-3D. The 4A-3D stratification assigns all different management areas into separate strata for both the North and South. There is less difference in Quillback CPUE between management areas; CPUE for this species varies primarily by depth. Nonetheless, the additional area stratification is not expected to negatively affect survey precision for Quillback.

Post-stratification analyses were conducted to calculate sample statistics for the PHMA survey using the 4 area-depth stratification options (Ault et al. 1999). Annual non-stratified and stratified mean CPUE and CVs were compared to assess possible gains in survey precision for each option. Stratification options that excluded sets in the deep strata (1A-2D, 2A-2D, 3A-2D, 4A-2D) were also evaluated, as Quillback are rarely caught in the 151-260 m depth range (Fig. B.2). The CV and CPUE were calculated using both the measured counts/450 hooks and the estimated weights/450 hooks to evaluate the potential for additional variability resulting from using weights rather than number of fish. Annual mean catch rates $\bar{y}_{h,y}$ and sampling variances $s^2_{h,y}$ for each stratum and year were used to calculate stratified means $\bar{y}_{str,y}$, variance $V(\bar{y}_{str,y})$ and the coefficient of variation of the stratified mean $CV(\bar{y}_{str,y})$ for each stratification option using standard Cochran (1977) estimators:

$$\bar{y}_{str,y} = \sum_{h=1}^{L} W_h \bar{y}_{h,y} \quad (1)$$

$$V(\bar{y}_{str,y}) = \sum_{h=1}^{L} W_h^2 \frac{s^2_{h,y}}{n_{h,y}} \left(1 - \frac{n_{h,y}}{N_h}\right) \quad (2)$$

$$s^2_{h,y} = \sum_{i=1}^{n_{h,y}} \frac{(y_{h,y,i} - \bar{y}_{h,y})^2}{(n_{h,y} - 1)} \quad (3)$$

$$CV(\bar{y}_{str,y}) = \frac{\sqrt{V(\bar{y}_{str,y})}}{\bar{y}_{str,y}} \quad (4)$$

where $h = \{1,2,\ldots,L\}$ are the number of strata and $i = \{1,2,\ldots,n_{h,y}\}$ are the individual sets in each strata and year. Stratified means and variances are weighted in proportion to the total N_h number of 2 km x 2 km blocks in each h stratum relative to the number of 2 km x 2 km blocks in the entire sampling space N, giving stratum weight $W_h = \frac{N_h}{N}$. The number of 2 km x 2 km blocks and approximate areas for stratification options 1A-3D, 2A-3D, 3A-3D and 4A-3D are shown in Tables 2.1-2.4. Certain strata had less than 2 sets in some years, in which case stratified statistics were recalculated excluding sets from those strata. This applied to the deep strata in area 3C in 2009 and the shallow strata in area 5B (North) in 2006 and 2008. The 2007 and 2009 sets in 5C were excluded from CPUE estimates because 5C is outside the Southern survey strata.

Sample allocation among strata can also improve survey precision, often more than geographic stratification (Cochran 1977; Smith and Gavaris 1993). We calculate the proportion of sets that should be allocated to different strata using 2 sample allocation options: 1) allocating samples among strata in proportion to stratum area (Area-based allocation), where $n_{h,y} = W_h n_y$, and 2) stratum area times the standard deviation, where $n_{h,y} = \frac{W_h s_{h,y} n_y}{\sum W_h s_{h,y}}$ (Optimal allocation).

Area-based allocation is the easiest approach for improving survey precision (Smith and Gavaris 1993), while optimal allocation minimizes expected variance (Cochran 1977). Optimal allocation requires an estimate of strata standard deviations, which can be obtained from previous surveys, pilot studies, or commercial fisheries data (Kimura and Somerton 2006). Following this approach, we used the mean of the standard deviation in the strata for all available survey years to calculate optimal allocation.

2.2.3 Power analysis

Power analyses are used to estimate the probability that the PHMA survey will successfully detect changes in rockfish populations over different timeframes. We tested 18 different scenarios, comprised of 6 different population trends (increases and declines of 10%, 25%, and 50%), and 3 different timeframes (10, 15, and 20 years). For each scenario, we simulated biennial sampling with 196 sets (the median number of realized sets on the PHMA survey) per year over different CVs ranging from 0-60%. We used a Monte Carlo simulation approach (as described in Gibbs et al. 1998), with 1000 simulations for each scenario where each simulation has the following steps:

1. Establish a baseline population index using an exponential model that assumes annual percent change in abundance is constant throughout the timeframe, such that $N_t = N_0 e^{rt}$, where N_0 is the initial population size, N_t is the population size at year t and r is the population growth rate. When the population index is transformed to the log scale we have a linear relationship of the form: $\log N_t = \log N_0 + rt$

2. Simulate a mean sampling index of abundance $\bar{N}_t$ for each sampling year, which is calculated from $n = 1,2,...,196$ samples each year:

$$\bar{N}_t = \sum_{n=1}^{196} \frac{\hat{N}_{t,n}}{196}$$

$$\hat{N}_{t,n} = N_t \exp(\varepsilon_{t,n})$$

$$\varepsilon_{t,n} \sim N(0, \sigma_{\log N})$$

$$\sigma_{\log N} = \log(1 + nCV^2)$$

where $\sigma_{\log N_t}$ is the variance of the log-transformed index of abundance, which is estimated from the CV and sample size.

3. Fit a linear regression of the $\log \hat{N}_t$ abundance versus sampling year of the form: $\log \hat{N}_t = \beta_0 + \beta_1 t + \varepsilon$, where β_0 and β_1 represent estimates of $\log N_0$ and r, respectively.

4. Evaluate detection of a population trend using two-sided t-test.

5. Repeat steps 2-4 for 1000 simulations, and determine the proportion of simulations that correctly detect a trend. This proportion is an estimate of the statistical power of the survey design and reflects the probability of correctly detecting a population trend when one is present.

Sampling years were based on the historical surveys in the Northern survey area such that sampling occurred in years (1,3,5,7,10,12,14,16,18 and 20) of the simulations, accounting for the skipped survey year in 2013 (i.e. year 8). We tested for evidence of non-zero slopes in populations using two-sided t-tests for values of $\alpha = 0.05,\ 0.10,\ \text{and}\ 0.20$. The α level is the accepted threshold for false positives or Type I errors, which is the probability of detecting a trend when there is none. Much of the scientific literature uses $\alpha = 0.05$, however Gibbs et al. (1998) recommend that monitoring programs for animal populations should consider higher α levels of up to 0.20 to allow for increased statistical power for detecting population increases or declines. The increased α level allows for a higher probability of falsely detecting changes in the population, which Gibbs et al. (1998) suggest is a reasonable trade-off to reduce the frequency that important changes in the population are not detected.

Note that the power analyses only accounts for sampling variance of the mean estimate of survey indices within each year, which is the result of observation error in a year (Stanley et al. 2007). The true population in each simulation is generated using a deterministic exponential model without error (i.e. does not represent process error arising from natural variability in a population; Hatch 2003; Maunder and Piner 2014).

2.3 RESULTS

2.3.1 Survey sampling frame

Of the 170 IPHC stations, only 59 recorded Yelloweye in at least 50% of survey years. There are 85 stations with Yelloweye in at least 3 years, 114 stations with Yelloweye in at least 1 year and 56 stations which have never caught Yelloweye Rockfish from 1998-2016. Almost all the stations that have caught only 1 or 0 Yelloweye are in locations that are excluded from the PHMA survey (Fig. 2.7). This indicates that, for the most part, survey resources are not being used to survey areas outside of Yelloweye habitats where there is high probability of zero CPUE. There are a few IPHC stations that never catch Yelloweye located on the edges of PHMA survey strata in areas 3C, 3D, 5A and 5BC (at 5B/5C border near Haida Gwaii)

Some of the IPHC stations that regularly encounter Yelloweye are not covered in the PHMA survey. There are 14 stations in 5C and 16 stations in 5B with Yelloweye catch in at least 3 years that are in areas not covered by the PHMA survey sampling frame. Many of these stations cover large areas that include adjacent IPHC stations that have encountered Yelloweye in at least 50% of years surveyed (Fig. 2.7). In addition, there are also 6 stations in 3C, 5 stations in 5A and 2 stations in 5D with Yelloweye catch in at least 3 years that are excluded from the PHMA survey. Figure 2.7 highlights all stations that have caught Yelloweye in at least 3 years that are excluded from the PHMA sampling frame. These findings indicate that some Yelloweye habitats are not covered by the PHMA survey and that 5D, 5C, 5B, 5A, and 3C could be underweighted in calculations of coastwide or north/south indices of abundance.

The distribution of Yelloweye and Quillback catches from longline hook and trap fisheries also indicate that several areas in 5C, 5B, 5A and 3C with >1 t catch from 2006-2016 are not covered by the PHMA survey (Fig 2.8-2.9), which is consistent with the areas identified from the IPHC survey. There are also several 18.5 km x 18.5 km grid cells in 5D with Quillback catches >1 t over the 2006-2016 period that are not covered by the PHMA survey grid (Fig. 2.9). Note that the commercial catch data are aggregated over 18.5 km x 18.5 km grids and thus may overestimate the habitat area in each grid cell (i.e. catches may be from a smaller area within each cell).

2.3.2 Survey precision

Both depth (1A-3D) and area stratifications (2A-3D, 3A-3D, 4A-3D) improved survey precision for Yelloweye Rockfish in the northern survey area. The largest gains in precision were achieved from changing the stratification from 1A-3D (no area stratum, 3 depth strata) to 2A-3D (2 area strata, 3 depth strata) to account for differences in catch rates between 5BE and 5CD. There were limited gains in precision from using 3A-3D or 4A-3D relative to the 2A-3D stratification, all of which performed similarly for the northern survey area with mean annual CVs of 9.8-10.0 and 10.2-10.5 for CPUEs measured in counts/450 hooks and kg/450 hooks, respectively (Table 2.5, Figs. 2.10-2.11). In the southern area, depth stratification provided the largest gain in precision for survey indices, while area stratifications offered smaller improvements. All 4 stratification options achieved similar outcomes in the Southern survey area, with mean annual CVs between 11.6-12.1 and 11.9-12.5, for CPUEs measured in counts/450 hooks and kg/450 hooks, respectively (Table 2.5, Figs. 2.10-2.11).

All 8 area-depth stratification options we explored for Quillback Rockfish performed similarly in the northern and southern survey areas, and improved precision relative to calculations without stratification. Mean annual CVs ranged between 8.5-8.6 and 8.7-8.8 for CPUEs measured in counts/450 hooks and kg/450 hooks for the North, respectively (Table 2.6, Figs. 2.12-2.14). In the South, mean annual CVs for Quillback under the 8 stratification options ranged between 10.9-11.4 and 11.2-11.5 for CPUEs measured in counts/450 hooks and kg/450 hooks, respectively. Inclusion of the shallow and medium depth strata (e.g. moving from no stratification to 1A-2D) provides only a small improvement in CVs when the deep stratum is excluded from calculations (Fig. 2.14). Thus, for Quillback, the major improvement in survey precision comes from including the deep strata (151-260m), as similar CVs are obtained if sets from the deep strata are removed prior to calculating mean CPUE. There is little improvement in survey precision from area-stratification or depth stratification for 20-150 m depth range. The inclusion of the deep strata sets also leads to lower indices of abundance for Quillback (Fig. 2.12-2.14).

The historical, area-based, and optimal allocation for sampling under the 4A-3D stratification options for Yelloweye and Quillback are presented in Tables 2.7-2.8. The average historical allocation is similar to the area-based allocation for most stratification options. This is expected, given that historical sampling has been allocated in proportion to the number of blocks in each depth strata and management area (Table 1.3). The optimal allocations differ for each stratification scheme and species. For Yelloweye, optimal allocation for most areas involves re-allocating samples from the shallow strata to deeper waters and areas with higher catch rates. The largest increases in sampling occur for stratum #3 (5E 151-260m) in the North and stratum

#6 (5A4B 151-260m) in the South. For Quillback, the optimal allocation reallocates samples from deep strata to medium and shallow strata. The largest increases in sampling occur for stratum #5 (5D 71-150 m) in the North and stratum #2 (5BC 71-150 m) in the South.

To explore the multi-species utility of the survey, mean CPUE and CVs under the different stratification options were calculated for other rockfish species commonly encountered on the survey. Canary, Silvergrey and Rosethorn all had mean CVs of 20% or lower for both northern and southern survey areas, while Greenstriped, Redbanded, China, Tiger, and Copper rockfishes all had mean CVs of 30% or lower (Fig. 2.15, Table 2.9). This suggests that sampling allocation and stratification can be optimized to improve survey precision for multi-species target CVs.

2.3.3 Power analysis

The results of the power analyses are shown in Fig. 2.16. As expected, the probability of detecting population trends increases with monitoring time, α level, and decreasing CV. The results indicate that for all time frames examined, there is greater than 80% probability of detecting a 50% increase or decrease in the population for a CV of 10%, with $\alpha > 0.05$. The probability of detection is higher for a 50% decrease than for a 50% increase because the annual rate of change is greater (i.e. steeper slope) for the decreasing trend. For example, a 50 % population decline over 10 years corresponds to a -7.4% decline in abundance each year, while a 50% population increase over 10 years corresponds to a 4.6% increase in abundance each year.

The probability of detecting a 25% change in either direction after 10 years is lower, with a 74% probability of detecting a 25% decline and a 56% probability of detecting a 25% increase over a 10-year period, for $\alpha = 0.10$ and a 10% CV (Figure 2.16b). Despite lower statistical power for the 10-year timeframe, the estimated trends were still within 50% of the true trend in 94% and 70% of simulation cases for 25% declines and 25% increases over 10 years, respectively (Fig 2.17-2.18). The statistical power is greater for a 15-year timeframe, with an 87% and 71% chance of detecting a 25% decline and 25% increase over 15 years, respectively, for $\alpha = 0.10$ and a 10% CV (Fig. 2.16e).

Our results indicate that the PHMA survey has a low probability of detecting and correctly estimating the targeted 13% population increase over 15-years as proposed under the rebuilding plan for Yelloweye (DFO 2015a). There is low statistical power for detecting a 12.5% increase or decrease in the population at a 10% CV over 10-20 years (Fig 2.16). Simulations over a 15-year timeframe with a CV of 10% had estimated trends that were within 50% of the true trend in only 57% and 45% of simulation cases for 12.5% decreases and increases, respectively (Fig 2.17-2.18). For $\alpha = 0.10$, there is only 32% probability of detecting a 12.5% increase over a 15-year period for a 10% CV. As Yelloweye and Quillback CVs from stratified means are in the 8-14% range, the results from the power analysis indicate the PHMA survey has a statistical power > 80% for detecting 50% population changes over 10 years and 25% changes over 15-20 years, depending on α level (i.e. tolerance for false positives).

2.4 DISCUSSION

Overall, we found high survey precision for Yelloweye, Quillback, Canary, Silvergrey and Rosethorn Rockfish (Table 2.9, Fig. 2.15), which are the species encountered in the greatest proportion of survey sets (Table 1.1). Survey precision for Yelloweye and Quillback rockfishes is greatest with mean CVs of 8-11% and 10-12%, respectively, for the 4A-3D stratification in Northern and Southern survey areas. Survey precision for Canary, Silvergrey and Rosethorn were also high with mean CVs ≤ 20%. The precision in the PHMA survey indices for these 5 rockfish species are similar to the highest precision indices generated on the Queen Charlotte Sound groundfish bottom trawl survey, which range from 10-20% for the top 13 species (Stanley et al. 2004). PHMA indices are higher than those obtained for Yelloweye Rockfish (32-74%), Quillback Rockfish (34-54%), Canary Rockfish (38-55%), Silvergrey (22-34%) and Rosethorn (15-44%) throughout the 4 areas surveyed on the synoptic groundfish bottom trawl survey (DFO GIAB Presentation, unpublished data). The PHMA survey indices for Yelloweye are also more precise than those from the IPHC survey index that were used in the 2014 assessment, which ranged from 18-26% and excluded IPHC stations from the West Coast of Vancouver Island (Yamanaka et al. 2018 - Appendix B). Mean CVs for PHMA survey indices for Greenstriped and Redbanded rockfishes are 17-21% and 22-23% for the 4A-3D stratification, which are similar to average CVs from the trawl survey ranging from 22-40% for Greenstriped and 18-26% for Redbanded for different areas (DFO GIAB Presentation, unpublished data). PHMA survey indices for hard bottom rockfish, such as China (21-24%), Tiger (22-29%) and Copper Rockfish (25-27%), are much more precise than those encountered on the trawl survey, which range from 53-100%.

Power analyses indicated there is adequate statistical power (>80 %) for detecting at least a 50% change in the population for most species with CVs < 30% over 10-20 year period, depending on the tolerance for false positives. There is also adequate statistical power (>80%) for detecting 25% population declines for species with CVs <20% over a 20-year period if the tolerance for false positives is $\geq$ 10%. Despite the high survey precision for Yelloweye and Quillback rockfishes (8-12% CV), there is poor statistical power (<80% probability) of detecting population changes of 12.5% over 15 or 20 years. This indicates that even if the Yelloweye population increases 13% over the next 15 years and achieves the primary rebuilding objective to grow out of the critical zone, the survey is unlikely to detect this change in the population with any certainty. Given this information the timeframe for rebuilding objectives for Yelloweye may need to be extended so that progress towards objectives can be reliably monitored. In Australia, rebuilding timeframes are established based on the minimum of (*i*) the mean generation time plus 10 years or (*ii*) three times the mean generation time (Haddon et al. 2013). Time horizons for achieving rockfish rebuilding targets in the US are often over several decades (Punt and Ralston 2007, Wetzel and Punt 2016). In the US the maximum time horizon (T_{MAX}) for rebuilding rockfish species must be set at (T_{MIN}), the minimum amount of time a stock can be rebuilt, plus one mean generation time (Wetzel and Punt 2016). Wetzel and Punt (2016) estimated rebuilding timeframes of 34-44 years and 80-105 years for medium-lived (Greenstriped and Widow rockfishes) and long-lived rockfish species (Yelloweye and Canary rockfishes), respectively, depending on the rebuilding strategy used. They found that rebuilding plans starting with a higher probability of rebuilding (>60%) performed better with less variability in catch, than rebuilding plans that aimed to maintain a 50% probability of rebuilding. These findings highlight the need to regularly evaluate rebuilding progress and allow for some flexibility to revise timelines based on new assessment information.

The PHMA longline survey provides catch rate estimates and biological sampling for multiple rockfish species but lacks clear objectives for each species. The survey was initially designed to target Yelloweye and Quillback rockfishes, but is now being considered for indexing other species. It is not currently clear what species are the highest priorities for generating abundance indices. For some inshore rockfish species (e.g. Copper, China, and Tiger) the PHMA survey indices may be the only reliable biomass indices available for future stock assessments. For other rockfish species (Yelloweye, Quillback, Canary, Silvergrey, and Rosethorn) indices with longer time series and higher observation errors in catch rates are available from the IPHC or the groundfish trawl surveys, which could be sufficient, depending on assessment needs. For example, the 2014 Silvergrey assessment is fit with groundfish synoptic trawl survey data (DFO 2014b). Tolerance for uncertainty in Silvergrey indices may be greater than those for other species whose stock status is near or below limit reference points. Other species such as Redbanded Rockfish, may have longer time series with higher precision from IPHC or trawl surveys, in which case they may not be desirable targets for indexing on the PHMA survey.

2.5 RECOMMENDATIONS

1. Adopt a standardized protocol for generating PHMA survey indices

High Priority

There is currently no clearly established protocol for converting the raw PHMA survey data into abundance indices. Different approaches have been used to convert the raw survey data into indices of abundance for stock assessment. The most recent Yelloweye assessment (Yamanaka et al. 2018 - Appendix C) uses a multinomial exponential model that accounts for interspecies hook competition (Somerton 1995; Etienne 2013). Other approaches have calculated arithmetic mean CPUE by management area (King et al. 2015) or applied the swept-area indices methodology developed for the synoptic bottom trawl groundfish surveys (Lochead and Yamanaka 2004; King et al. 2013).

In this report, we document procedures for processing the PHMA data and generating indices using standard Cochran estimators for stratified random survey statistics. We've proposed stratifying by groundfish management area as well as by the three depth categories for generating survey indices moving forward (see recommendation 2).

Interspecies hook competition was not evaluated in this report; however, the PHMA survey hook by hook sampling data can be analyzed to assess differences in catchabilities within area-depth strata and whether hook competition adjustments factors should be applied to standardize survey indices (Clark 2008; Webster and Hare 2010). If the effect of hook competition is similar across areas than adjustments for hook competition may not be necessary (Clark 2008).

2. Use the 4A-3D stratification in the North and South survey areas.

High Priority

The 4-Area and 3-Depth stratification option improves survey precision and ensures sampling in all outside management areas. Our comparison of mean CPUE and CVs under 4 stratification options for Northern and Southern survey areas indicates that the current 3-depth stratification reduces CVs for both Yelloweye and Quillback rockfishes. Using additional area stratification further improved CVs for Yelloweye Rockfish, particularly in the Northern area, but yielded marginal reductions in CVs for Quillback. The largest gains in survey precision for

Yelloweye were realized under area stratification encompassing the west coast and southern tip of Haida Gwaii (5BE), where average Yelloweye catch rates are much higher than those in Dixon Entrance and Hecate Strait (5CD, Fig. A.2). Similar CVs were obtained using the 2A-3D, 3A-3D or 4A-3D stratifications for all rockfish with current stratum weightings. The 4A-3D stratification separates all management areas into distinct strata (combining 5A and 4B), which may be desirable since annual Yelloweye TACs are currently allocated to different management areas in proportion to spatial CPUE trends in each area from the PHMA survey.

3. Allocate sets in proportion to the number of survey blocks in each area-depth stratum, with a minimum of 3 sets allocated to each stratum.

High Priority

A minimum of 2 sets in each stratum are required to calculate mean and variance statistics, but 3 sets provides a buffer in case a block is unfishable. Historically, there are years in which fewer than 2 sets have been allocated for deep strata in area 3C and the shallow strata in 5B (North) because they comprise less than 1% of the survey area. If the key species of interest are identified, additional analyses can be used to optimize sampling allocation for multiple species (see other considerations 1-2).

Note: Since survey blocks in area 5A and 4B (in the northern part of PFMA 12) are combined into 1 stratum in the recommended 4A-3D southern stratification, a random selection of their combined blocks may not allocate sets in 4B every year. If it is important to maintain sets in 4B every year, the historical approach of allocating sets in proportion to the number of blocks in each depth-management area combination may be preferred.

4. Identify the proportion of Yelloweye and Quillback habitat that is included in each survey stratum.

Low Priority

It is important that the PHMA sampling frame adequately captures the distribution and abundance of the population of interest, to avoid bias in the survey index. Fine-scale mapping may identify stratum areas that are over- or under-represented in the survey. For example, the PHMA survey sampling frame covers most of the areas with high CPUE in 5E, 5D, 5A, and 3D, but many of the IPHC stations in 5B, 5C, and 3C that regularly encounter Yelloweye are outside areas sampled by the PHMA survey. The 2015 Yelloweye assessment estimated Yelloweye habitat (area of occupancy) of 93 618 km^2 based on 1996-2015 commercial catches aggregated in 5 km^2 cells (DFO 2015b). The PHMA survey covers approximately 25% of this habitat; however, the combination of IPHC and PHMA survey areas appear to cover most Yelloweye habitat and both surveys will likely be used in future rockfish assessments. The PHMA survey frame could be evaluated to ensure appropriate spatial weightings for calculating survey indices. For example, if area 5C accounts for 55% of the Yelloweye Rockfish habitat in the northern survey area but is weighted 45% in stratified index calculations (current weighting based on the number of grid cells in that stratum), abundance trends in 5C would be under-weighted in the northern index. Alternative stratum weightings could be evaluated that account for excluded habitat in the PHMA survey by weighting stratum based on the habitat area rather than the number of sampling blocks in each stratum. This approach would assume that mean stratum CPUE is representative of abundance in non-surveyed habitats within the same stratum. This assumption could be tested by comparing IPHC CPUE trends in each stratum for stations inside and outside of the PHMA survey grid.

2.6 OTHER CONSIDERATIONS

1. Clarify survey objectives for different species

PHMA survey indices could be used for stock assessment of commonly caught inshore rockfish species. If the goals for each species are more clearly identified, the survey design and sampling allocation could be modified to optimize survey precision for multiple species. For example, Copper and China rockfishes are rarely encountered in strata deeper than 70 m, and thus a sampling strategy that allocated more sets in the shallow strata (20-70 m) could improve survey precision for shallower species. Canary Rockfish could also be a good candidate for indexing with the PHMA survey, since they are caught in a high proportion of sets (39%), have relatively low annual CVs for stratified means (13-26% in the North and 13-17% in the South, Fig 2.15) and commonly occur in all 3 depth strata. Silvergrey and Redbanded rockfishes are mostly caught in deeper water at depths from 80-390 m (DFO 2014b) and 130-425 m (Edwards et al. 2017), respectively, and are most frequently caught on the survey in the medium and deep depth strata (Table 1.1). If there are intentions to use the PHMA survey to index more deep-water species, expanding survey grounds to depths below 260 m should be considered.

Currently, there are 3 stated goals for the PHMA survey (DFO-PHMA 2016 - Appendix A).

i. Provide relative abundance indices for commonly caught species for use in stock assessment;
ii. Provide biological data such as sex, age, and size composition for inshore rockfish populations;
iii. Provide occurrence data for less-commonly caught species.

This paper addresses goal (i) by evaluating survey precision and the ability of the survey to detect trends in abundance for Yelloweye and Quillback rockfishes. The initial focus of the PHMA survey was to provide indices for stock assessment of outside Quillback and Yelloweye rockfishes; our analysis suggests it performs well for these species. While there is growing interest in using PHMA survey indices for stock assessment of other rockfish and some non-rockfish species, it is not immediately clear which of the above goals apply to the other species encountered on the survey. Yelloweye and Quillback are the most commonly caught rockfish species on the PHMA survey, while Canary, Silvergrey, Rosethorn, Redbanded, Greenstriped, China, Copper, and Tiger rockfish are encountered on more than 10% of sets (Table 1.1). Note also that Yelloweye, Redbanded, Quillback, Copper, China, Tiger, and Black rockfishes are currently listed as the priority species for biological sampling (Archipelago Marine Research 2016).

The PHMA survey could also focus on filling gaps in information and collecting data that is not provided by the other surveys in BC (e.g. IPHC, Synoptic Trawl, Sablefish Trap). A previous survey review (Cox 2014) indicated that the PHMA survey could be optimized to focus on generating indices of abundance for groundfish species that are not as well indexed by other surveys on the BC coast. It may also be valuable to focus more on rockfish species whose habitat and depth range is fully covered by the PHMA sampling frame. A detailed analysis comparing indices or available biological data for different species from the various surveys in BC is beyond the scope of the current report, but further investigation of data gaps would help inform where to best allocate resources.

2. Survey performance

Survey indices should be sufficiently precise to detect changes in a population over a short enough timeframe and with enough certainty to inform harvest strategies. We used CV (standard error/mean CPUE) as a measure of survey precision and conducted statistical power analyses to determine the probability of detecting population increases or declines of 10-50% over 10-20 years for CVs ranging from 0-60%. The power analysis (Fig. 2.16-2.18) can be used *a priori* to select the target CV that will allow detection of population trends within a tolerable range of uncertainty required for management decisions. Target CVs of < 20% are often considered desirable for fisheries surveys; however, it varies by species, current stock status, tolerance for further declines, and economic objectives of the fishery. Thus, a CV < 15% may be required for Yelloweye Rockfish while a CV of 20-40% might be adequate for another species, depending on the level of population change that the survey aims to detect. Once a target CV is identified for each species of interest, further analysis can be conducted to reveal the multi-species trade-offs involved in achieving target CVs for more than Yelloweye and Quillback.

3. Clarify management needs

The Sustainable Fisheries Framework requires that rebuilding plans grow stocks out of critical zone within 1.5 - 2 generations or possibly longer for long-lived species, which would suggest longer rebuilding time horizons than the current 15-year rebuilding timeframe used for Yelloweye. For example, Wetzel and Punt (2016) used mean generation times of 40 years for medium-lived rockfish (Greenstriped and Widow rockfishes) and 50 years for long-lived rockfish (Yelloweye and Canary rockfishes) for determining target rebuilding timelines in an evaluation of different rebuilding strategies. Benson et al. (2016) evaluated alternative approaches to rebuilding for US fisheries, and found that harvest control rules perform as well, if not better than rebuilding approaches that rely on estimated schedules of rebuilding times and fishing mortalities. The most efficient rebuilding approach may therefore be a formal strategy that specifies repeatable assessment methods and decision rules for setting annual TACs (Smith et al. 2013). There are three key elements needed to develop a harvest strategy:

1) Establish a fishery diagnosis (e.g. data availability, appropriate assessment methods, assessment of stock status, threats to the fishery) (Dowling et al. 2016)
2) Define measurable conservation and economic objectives for the fishery (e.g. limit and target reference points) (Restrepo et al. 1998; Benson and Stephenson 2017)
3) Identify specific management actions that will achieve objectives (e.g. linking surveys to TACs, harvest control rules, spatial management) (Haddon et al. 2013; Smith et al. 2013)

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TABLES FOR PART 1 - DATA SUMMARY

Table 1.1. Total number of sets with catch for different rockfish species from 2006-2016 PHMA survey sets by different depth strata (DS1 = 20-70 m, DS2 = 71-150 m, DS3 = 151-260 m). Bold numbers highlight instances where > 90% of catch or sets for a species occur in only 1 or 2 depth strata (for species present in at least 10% of sets)

Species	Number of Sets Caught		Catch (numbers)	% Sets with Species by Depth Strata			% Total Catch by Depth Strata (numbers)		
	n	%		DS1	DS2	DS3	DS1	DS2	DS3
Yelloweye Rockfish	1284	65.8	36,740	23	50	27	10	**49**	**41**
Quillback Rockfish	1013	51.9	20,286	**43**	**55**	2	**45**	**54**	0.5
Canary Rockfish	762	39.1	6,697	29	49	22	19	59	22
Silvergrey Rockfish	684	35.1	6,566	11	48	42	2	**40**	**58**
Rosethorn Rockfish	444	22.8	1,553	6	**68**	**26**	3	**79**	**18**
Redbanded Rockfish	403	20.7	7,524	1	9	**91**	0.1	3	**96**
Greenstriped Rockfish	334	17.1	1,014	1	**46**	**53**	0.4	**37**	**62**
China Rockfish	278	14.3	2,372	**95**	4	0.4	**98**	2	0.04
Copper Rockfish	235	12.1	1,816	**97**	3	0.4	**99**	1	0.06
Tiger Rockfish	217	11.1	436	**41**	**52**	6	**42**	**54**	4
Yellowtail Rockfish	182	9.3	433	19	49	31	16	56	28
Vermilion Rockfish	127	6.5	378	94	5	1	97	2	0.3
Shortspine Thornyhead	100	5.1	573	2	5	93	0.3	6	94
Bocaccio	93	4.8	202	2	49	48	1	46	53
Rougheye Rockfish	88	4.5	294	0	7	93	0	2	98
Yellowmouth Rockfish	52	2.7	372	0	0	100	0	0	100
Black Rockfish	38	1.9	110	76	18	5	88	10	2
Dusky Rockfish	19	1.0	62	16	37	47	8	56	35
Redstripe Rockfish	19	1.0	22	16	53	32	14	55	32
Shortraker Rockfish	17	0.9	56	0	0	100	0	0	100
Widow Rockfish	10	0.5	19	10	40	50	11	21	68
Blackspotted Rockfish	8	0.4	24	0	0	100	0	0	100
Pacific Ocean Perch	7	0.4	17	0	0	100	0	0	100
Darkblotched Rockfish	6	0.3	8	0	0	100	0	0	100
Sharpchin Rockfish	6	0.3	6	0	0	100	0	0	100
Blue Rockfish	5	0.3	9	80	0	20	89	0	11
Deacon Rockfish	3	0.2	14	100	0	0	100	0	0
Chilipepper Rockfish	1	0.1	1	0	100	0	0	100	0
Splitnose Rockfish	1	0.1	1	0	100	0	0	100	0
Unidentified rockfishes	12	0.6	16	67	17	17	69	19	13

Table 1.2. Number of 2 km x 2 km blocks in PHMA survey sampling frame for different management areas and depth strata

PHMA Survey Area	Management Area	Depth Strata	Number of Blocks	Area (km^2)	% of total
North					
	5B	20 to 70 m	24	96	0.8
	5B	71 to 150 m	54	216	1.7
	5B	151 to 260 m	85	340	2.7
	5C	20 to 70 m	319	1,276	10.3
	5C	71 to 150 m	651	2,604	21.0
	5C	151 to 260 m	429	1,716	13.8
	5D	20 to 70 m	276	1,104	8.9
	5D	71 to 150 m	380	1,520	12.2
	5D	151 to 260 m	146	584	4.7
	5E	20 to 70 m	202	808	6.5
	5E	71 to 150 m	281	1,124	9.0
	5E	151 to 260 m	258	1,032	8.3
		TOTAL	3,105	12,420	100.0
South					
	3C	20 to 70 m	231	924	8.1
	3C	71 to 150 m	176	704	6.2
	3C	151 to 260 m	25	100	0.9
	3D	20 to 70 m	344	1,376	12.1
	3D	71 to 150 m	416	1,664	14.6
	3D	151 to 260 m	132	528	4.6
	4B	20 to 70 m	14	56	0.5
	4B	71 to 150 m	15	60	0.5
	4B	151 to 260 m	5	20	0.2
	5A	20 to 70 m	269	1,076	9.4
	5A	71 to 150 m	443	1,772	15.5
	5A	151 to 260 m	201	804	7.1
	5B	20 to 70 m	130	520	4.6
	5B	71 to 150 m	324	1,296	11.4
	5B	151 to 260 m	124	496	4.4
		TOTAL	2,849	11,396	100.0

Table 1.3. Number of usable sets for CPUE calculations in different management areas and different depth strata for PHMA surveys from 2006-2016.

Survey Area	Year	By Management Area								By Depth Strata (m)			CPUE Sets
		3C	3D	4B	5A	5B	5C	5D	5E	20 -70	71 -150	151 - 260	
North													
	2006					11	79	57	49	39	87	62	188
	2008					11	82	52	50	43	84	60	187
	2010					10	87	53	47	50	83	58	191
	2012					10	90	51	45	50	89	56	195
	2015					10	88	50	47	49	88	58	195
South													
	2007	25	57	2	61	37	14			48	83	64	195
	2009	17	55	1	60	37	16			42	79	61	182
	2011	30	61	2	63	41				69	93	34	196
	2014	30	59	2	64	39				66	93	35	194
	2016	30	62	2	65	38				69	95	33	197

Table 1.4. Number of sets completed by different vessels on PHMA survey from 2006-2016

Year	Vessel	Number of Sets
2006	ARGYLE #1	80
	BANKER II	55
	QUATSINO STAR	61
2007	ARGYLE #1	66
	BANKER II	64
	VIKING VENTURE	66
2008	ARGYLE #1	66
	BANKER II	64
	QUATSINO STAR	65
2009	ARGYLE #1	62
	BANKER II	62
	QUATSINO STAR	62
2010	BANKER II	66
	PACIFIC AMBITION	65
	QUATSINO STAR	66
2011	BANKER II	65
	PACIFIC AMBITION	66
	QUATSINO STAR	66
2012	BANKER II	65
	PACIFIC AMBITION	65
	QUATSINO STAR	66
2014	BANKER II	64
	BOREALIS 1	65
	QUATSINO STAR	65
2015	BOREALIS 1	98
	PACIFIC AMBITION	98
2016	BANKER II	66
	BOREALIS 1	66
	PACIFIC AMBITION	65

Table 1.5. Mean weights (g) of individual fish by depth strata and year for Quillback Rockfish and Yelloweye Rockfish sampled in PHMA survey sets

Year	Quillback Rockfish			Yelloweye Rockfish		
	20-70 m	71-150 m	151-260 m	20-70 m	71-150 m	151-260 m
2006	983	1,196	959	2,873	3,296	3,559
2007	1,066	1,143		2,381	3,112	3,393
2008	955	1,147	1,183	3,169	3,321	3,759
2009	1,037	1,164	1,272	2,671	3,017	3,335
2010	915	1,134	955	2,932	3,272	3,487
2011	954	1,112		2,543	3,070	3,223
2012	971	1,097	1,008	2,965	3,373	3,703
2014	965	1,166	1,354	2,698	3,206	3,637
2015	900	1,065	909	2,770	3,257	3,526
2016	1,018	1,152	908	2,779	3,092	3,491

Table 1.6. Number of sets by depth strata after data processing to assign depth strata according to depth at set midpoints compared with original depth strata (DS) indicated in PHMA survey data for 2006-2016

Year	Depth strata (m)	Number of Sets			% of sets assigned to different DS in original dataset		
		Based on set midpoint depth	Original data	% match	20-70m	71-150m	151-260m
2006	20-70	44	41	93%		5%	2%
2006	71-150	88	79	90%	8%		2%
2006	150-260	64	57	89%	0%	11%	
2007	20-70	49	47	96%		4%	0%
2007	71-150	83	77	93%	7%		0%
2007	150-260	64	55	86%	0%	14%	
2008	20-70	44	43	98%		2%	0%
2008	71-150	87	80	92%	7%		1%
2008	150-260	64	56	88%	0%	13%	
2009	20-70	43	42	98%		2%	0%
2009	71-150	81	69	85%	15%		0%
2009	150-260	62	56	90%	2%	8%	
2010	20-70	52	52	100%		0%	0%
2010	71-150	86	85	99%	1%		0%
2010	150-260	59	57	97%	0%	3%	
2011	20-70	69	68	99%		1%	0%
2011	71-150	94	89	95%	3%		2%
2011	150-260	34	33	97%	0%	3%	
2012	20-70	51	50	98%		2%	0%
2012	71-150	89	87	98%	2%		0%
2012	150-260	56	55	98%	0%	2%	
2014	20-70	66	66	100%		0%	0%
2014	71-150	93	93	100%	0%		0%
2014	150-260	35	35	100%	0%	0%	
2015	20-70	50	50	100%		0%	0%
2015	71-150	88	88	100%	0%		0%
2015	150-260	58	58	100%	0%	0%	
2016	20-70	69	67	97%		3%	0%
2016	71-150	95	91	96%	3%		1%
2016	150-260	33	33	100%	0%	0%	

TABLES FOR PART 2 - SURVEY REVIEW

Table 2.1. Number of 2 km x 2 km sampling blocks for 1A-3D stratification in Northern and Southern survey areas

PHMA Survey Area	Strata Number	Management Areas	Area Strata	Depth Strata (m)	Number of Blocks	Area km^2	Proportional Allocation by Area (W_h)
North							
	1	5BCDE	1	20-70	821	3,284	26%
	2	5BCDE	1	71-150	1,366	5,464	44%
	3	5BCDE	1	151-260	918	3,672	30%
South							
	1	3CD4B5AB	1	20-70	988	3,952	35%
	2	3CD4B5AB	1	71-150	1,374	5,496	48%
	3	3CD4B5AB	1	151-260	487	1,948	17%

Table 2.2. Number of 2 km x 2 km sampling blocks for 2A-3D stratification in Northern and Southern survey areas

PHMA Survey Area	Strata Number	Management Areas	Area strata	Depth Strata (m)	Number of Blocks	Area km^2	Proportional Allocation by Area (W_h)
North							
	1	5BE	1	20-70	226	904	7%
	2	5BE	1	71-150	335	1,340	11%
	3	5BE	1	151-260	343	1,372	11%
	4	5CD	2	20-70	595	2,380	19%
	5	5CD	2	71-150	1,031	4,124	33%
	6	5CD	2	151-260	575	2,300	19%
South							
	1	3D4B5AB	1	20-70	757	3,028	27%
	2	3D4B5AB	1	71-150	1,198	4,792	42%
	3	3D4B5AB	1	151-260	462	1,848	16%
	4	3C	2	20-70	231	924	8%
	5	3C	2	71-150	176	704	6%
	6	3C	2	151-260	25	100	1%

Table 2.3. Number of 2 km x 2 km sampling blocks for 3A-3D stratification in Northern and Southern survey areas

PHMA Survey Area	Strata Number	Management Areas	Area strata	Depth Strata (m)	Number of Blocks	Area km^2	Proportional Allocation by Area (W_h)
North	1	5BE	1	20-70	226	904	7%
	2	5BE	1	71-150	335	1,340	11%
	3	5BE	1	151-260	343	1,372	11%
	4	5D	2	20-70	276	1,104	9%
	5	5D	2	71-150	380	1,520	12%
	6	5D	2	151-260	146	584	5%
	7	5C	3	20-70	319	1,276	10%
	8	5C	3	71-150	651	2,604	21%
	9	5C	3	151-260	429	1,716	14%
South							
	1	5B (north)	1	20-70	86	344	3%
	2	5B (north)	1	71-150	160	640	6%
	3	5B (north)	1	151-260	90	360	3%
	4	3D4B5AB	2	20-70	671	2,684	24%
	5	3D4B5AB	2	71-150	1038	4,152	36%
	6	3D4B5AB	2	151-260	372	1,488	13%
	7	3C	3	20-70	231	924	8%
	8	3C	3	71-150	176	704	6%
	9	3C	3	151-260	25	100	1%

Table 2.4. Number of 2 km x 2 km sampling blocks and area blocks for 4A-3D stratification for Northern and Southern survey areas

PHMA Survey Area	Strata Number	Management Areas	Area strata	Depth Strata (m)	Number of Blocks	Area km^2	Proportional Allocation by Area (W_h)
North							
	1	5E	1	20-70	202	808	7%
	2	5E	1	71-150	281	1,124	9%
	3	5E	1	151-260	258	1,032	8%
	4	5D	2	20-70	276	1,104	9%
	5	5D	2	71-150	380	1,520	12%
	6	5D	2	151-260	146	584	5%
	7	5C	3	20-70	319	1,276	10%
	8	5C	3	71-150	651	2,604	21%
	9	5C	3	151-260	429	1,716	14%
	10	5B	4	20-70	24	96	1%
	11	5B	4	71-150	54	216	2%
	12	5B	4	151-260	85	340	3%
South							
	1	5B	1	20-70	130	520	5%
	2	5B	1	71-150	324	1,296	11%
	3	5B	1	151-260	124	496	4%
	4	5A4B	2	20-70	283	1,132	10%
	5	5A4B	2	71-150	458	1,832	16%
	6	5A4B	2	151-260	206	824	7%
	7	3D	3	20-70	344	1,376	12%
	8	3D	3	71-150	416	1,664	15%
	9	3D	3	151-260	132	528	5%
	10	3C	4	20-70	231	924	8%
	11	3C	4	71-150	176	704	6%
	12	3C	4	151-260	25	100	1%

Table 2.5. Mean, minimum, and maximum of annual CVs (%) from 2006-2016 for stratified and non-stratified CPUE for Yelloweye Rockfish under different stratifications. CPUE indices are shown for both counts/450 hooks and kg/450 hooks

PHMA Survey Area	Stratification	CVs for CPUE (counts/450 hooks)			CVs for CPUE (kg/450 hooks)		
		mean	min.	max.	mean	min.	max.
North							
	none	12.8	11.3	14.4	13.4	12.1	15.4
	1A-3D	12.1	10.6	13.7	12.7	11.3	14.5
	2A-3D	10.0	8.0	11.6	10.5	8.6	12.6
	3A-3D	9.9	8.0	11.5	10.5	8.6	12.6
	4A-3D	9.8	8.0	11.2	10.2	8.5	12.1
South							
	none	13.4	11.7	14.4	13.9	12.2	15.1
	1A-3D	12.1	10.9	13.4	12.5	11.3	13.9
	2A-3D	11.9	10.7	13.1	12.2	11.1	13.7
	3A-3D	11.6	10.5	12.6	11.9	10.9	13.0
	4A-3D	11.6	10.4	12.8	11.9	10.7	13.2

Table 2.6. Mean, minimum, and maximum of annual CVs (%) from 2006-2016 for stratified and non-stratified CPUE for Quillback Rockfish under different stratifications. CPUE indices are shown for both counts/450 hooks and kg/450 hooks

PHMA Survey Area	Stratification	CVs for CPUE (counts/450 hooks)			CVs for CPUE (kg/450 hooks)		
		mean	min.	max.	mean	min.	max.
North							
	none	10.1	9.3	10.8	10.3	9.1	10.9
	1A-3D	8.6	7.8	9.3	8.8	7.7	9.4
	2A-3D	8.5	7.8	9.0	8.8	7.7	9.3
	3A-3D	8.5	7.8	8.9	8.7	7.6	9.4
	4A-3D	8.5	7.7	9.0	8.8	7.5	9.4
North (excluding deep strata)							
	none	9.0	8.2	9.6	9.2	8.0	9.6
	1A-2D	8.6	7.9	9.4	8.8	7.7	9.5
	2A-2D	8.6	7.9	9.0	8.8	7.7	9.3
	3A-2D	8.5	7.8	8.9	8.8	7.7	9.4
	4A-2D	8.6	7.8	9.1	8.8	7.6	9.4
South							
	none	12.5	11.0	14.1	12.6	11.3	14.1
	1A-3D	11.4	10.2	12.9	11.5	10.5	12.9
	2A-3D	11.3	10.3	12.6	11.4	10.5	12.7
	3A-3D	11.3	10.2	12.9	11.5	10.5	12.9
	4A-3D	10.9	9.9	11.9	11.2	10.4	12.1
South (excluding deep strata)							
	none	11.9	10.6	13.4	12.0	10.9	13.5
	1A-2D	11.4	10.2	13.0	11.5	10.5	13.0
	2A-2D	11.3	10.3	12.7	11.5	10.5	12.8
	3A-2D	11.3	10.2	12.9	11.5	10.5	13.0
	4A-2D	10.9	9.9	12.0	11.2	10.4	12.2

Table 2.7. Average historical allocation of sets for different depth strata under 4A-3D stratification compared with proportional and optimal allocations for Yelloweye Rockfish based on mean annual CPUEs (kg/450 hooks) and standard deviation (SD) from 2006-2016

PHMA Survey Area	Strata Number	Area	Depth Strata (m)	Strata Area km^2	Mean CPUE	Mean SD	Mean % sets with Zero Catch	Allocation Options		
								Historical	Area	Optimal
North										
	1	5E	20-70	808	61	76	10%	6%	7%	7%
	2	5E	71-150	1,124	205	153	1%	9%	9%	19%
	3	5E	151-260	1,032	257	239	15%	9%	8%	27%
	4	5D	20-70	1,104	9	17	54%	8%	9%	2%
	5	5D	71-150	1,520	26	46	39%	13%	12%	8%
	6	5D	151-260	584	13	21	62%	5%	5%	1%
	7	5C	20-70	1,276	17	22	28%	9%	10%	3%
	8	5C	71-150	2,604	40	51	15%	21%	21%	15%
	9	5C	151-260	1,716	21	34	46%	13%	14%	6%
	10	5B	20-70	96	120	194	0%	1%	1%	2%
	11	5B	71-150	216	191	184	0%	2%	2%	4%
	12	5B	151-260	340	136	179	22%	3%	3%	7%
South										
	1	5B	20-70	520	28	28	28%	4%	5%	2%
	2	5B	71-150	1,296	60	79	22%	11%	11%	13%
	3	5B	151-260	496	61	105	54%	5%	4%	7%
	4	5A4B	20-70	1,132	13	26	57%	9%	10%	4%
	5	5A4B	71-150	1,832	57	81	27%	16%	16%	19%
	6	5A4B	151-260	824	169	186	12%	9%	7%	19%
	7	3D	20-70	1,376	18	34	48%	11%	12%	6%
	8	3D	71-150	1,664	71	101	41%	14%	15%	21%
	9	3D	151-260	528	71	105	37%	6%	5%	7%
	10	3C	20-70	924	6	14	77%	7%	8%	2%
	11	3C	71-150	704	5	11	71%	6%	6%	1%
	12	3C	151-260	100	4	5	58%	1%	1%	0%

Table 2.8. Average historical allocation of sets for different depth strata under 4A-3D stratification compared with proportional and optimal allocations for Quillback Rockfish based on mean annual CPUEs (kg/450 hooks) and standard deviation (SD) from 2006-2016

PHMA Survey Area	Strata Number	Area Strata	Depth Strata (m)	Strata Area km^2	Mean CPUE	Mean SD	Mean % sets with Zero Catch	Allocation Options		
								Historical	Area	Optimal
North										
	1	5E	20-70	808	24.0	18.2	4%	6%	7%	9%
	2	5E	71-150	1,124	16.8	18.7	20%	9%	9%	12%
	3	5E	151-260	1,032	-	-	100%	9%	8%	0%
	4	5D	20-70	1,104	20.9	22.0	17%	8%	9%	14%
	5	5D	71-150	1,520	19.1	23.7	31%	13%	12%	21%
	6	5D	151-260	584	0.5	1.4	91%	5%	5%	0%
	7	5C	20-70	1,276	20.2	15.5	0%	9%	10%	12%
	8	5C	71-150	2,604	17.3	17.2	20%	21%	21%	26%
	9	5C	151-260	1,716	0.4	1.6	90%	13%	14%	2%
	10	5B	20-70	96	34.5	12.5	0%	1%	1%	1%
	11	5B	71-150	216	21.6	19.2	21%	2%	2%	2%
	12	5B	151-260	340	-	-	100%	3%	3%	0%
South										
	1	5B	20-70	520	17.1	12.7	6%	4%	5%	5%
	2	5B	71-150	1,296	15.6	20.4	41%	11%	11%	20%
	3	5B	151-260	496	0.3	0.9	90%	5%	4%	0%
	4	5A4B	20-70	1,132	11.9	12.0	25%	9%	10%	10%
	5	5A4B	71-150	1,832	10.1	15.1	44%	16%	16%	21%
	6	5A4B	151-260	824	-	-	100%	9%	7%	0%
	7	3D	20-70	1,376	10.2	12.0	34%	11%	12%	13%
	8	3D	71-150	1,664	6.9	12.1	62%	14%	15%	16%
	9	3D	151-260	528	0.0	0.1	98%	6%	5%	0%
	10	3C	20-70	924	11.2	13.8	37%	7%	8%	10%
	11	3C	71-150	704	3.4	8.2	72%	6%	6%	4%
	12	3C	151-260	100	-	-	100%	1%	1%	0%

Table 2.9. Mean annual CVs (%) from PHMA survey sets for different rockfish species for different stratification options compared with CVs from means with no stratification (ns). Species ordered based on average CV for 4A-3D in Northern and Southern survey areas

	Northern Area					Southern Area				
Species	1A-3D	2A-3D	3A-3D	4A-3D	ns	1A-3D	2A-3D	3A-3D	4A-3D	ns
Yelloweye	8.6	8.5	8.5	8.5	10	11	11	11	11	12
Quillback	12	10	10	10	13	12	12	12	12	13
Canary	18	18	18	18	19	15	15	15	15	16
Silvergrey	17	14	14	14	18	20	20	19	20	21
Rosethorn	18	17	17	17	19	19	19	19	19	20
Greenstriped	23	21	21	21	25	17	17	17	17	19
China	25	25	24	24	29	21	21	21	21	24
Redbanded	23	22	22	22	26	25	25	24	24	29
Tiger	22	22	22	22	23	30	30	30	29	30
Copper	26	27	26	27	30	25	25	25	25	28
Bocaccio	38	37	37	37	40	53	53	53	53	57
Rougheye	39	39	39	39	42	83	83	83	82	86

FIGURES FOR PART 1 - DATA SUMMARY

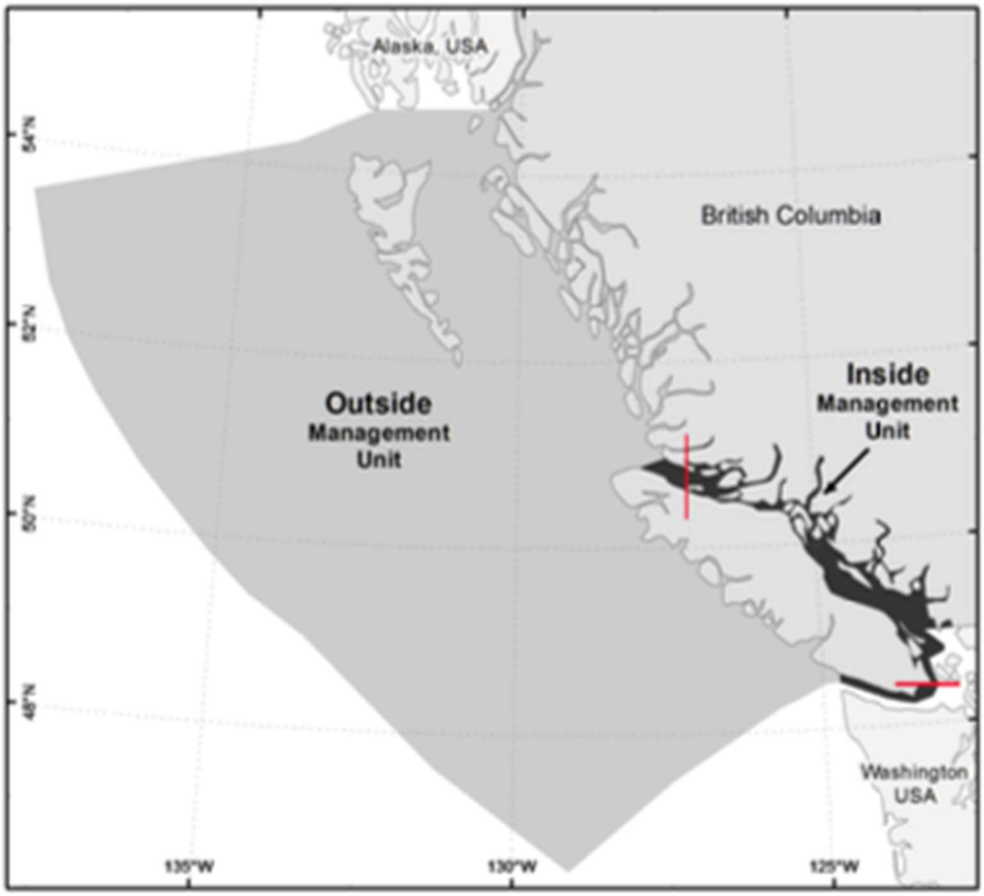

Figure 1.1. Outside and inside management units for Yelloweye and Quillback rockfishes in BC, and boundaries (red lines) for genetically distinct Yelloweye populations (Reproduction of map published in Yamanaka et al. 2018).

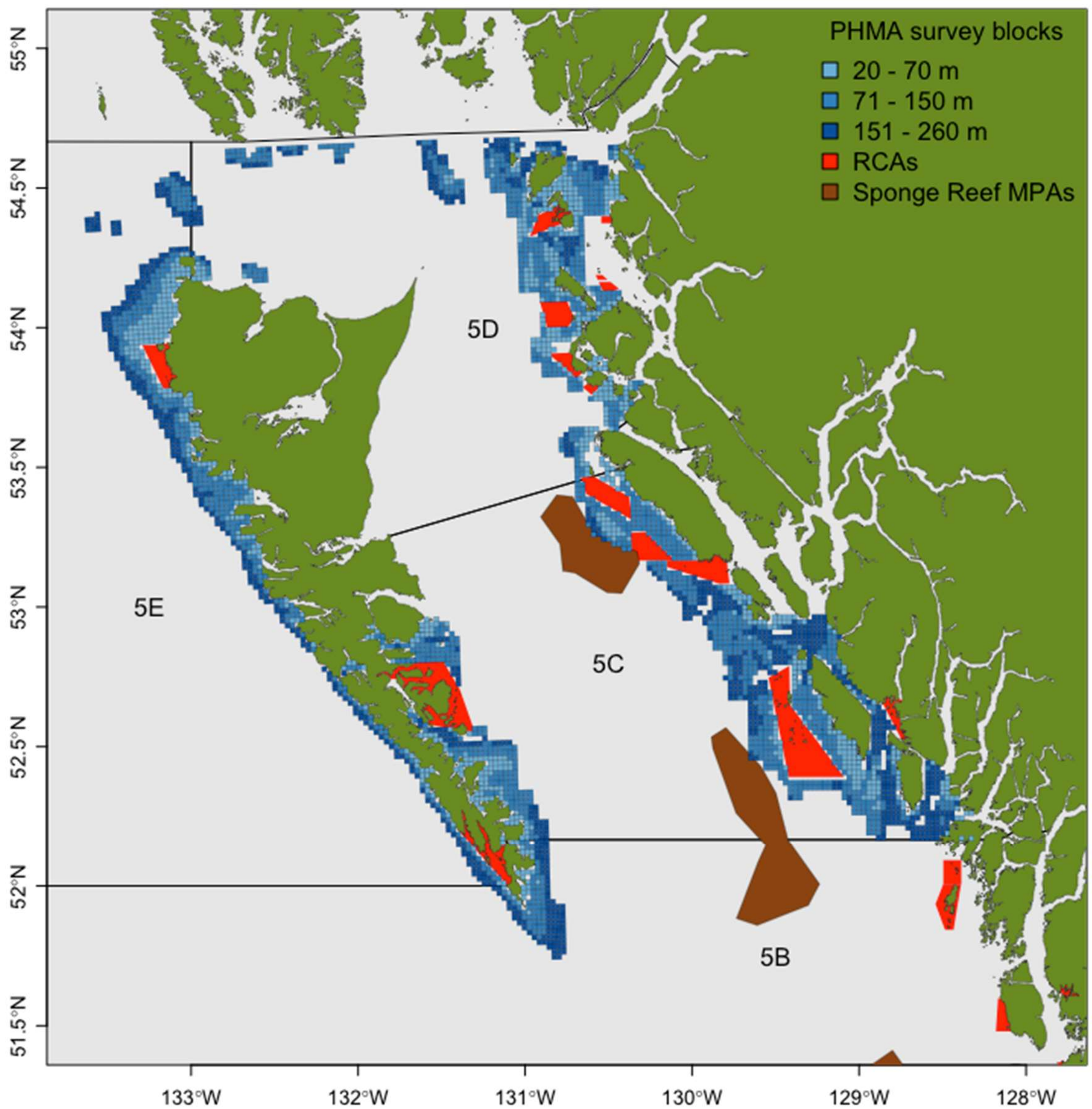

Figure 1.2. Map of 2 km x 2 km blocks for 3 depth strata for the PHMA survey grid in Northern BC.

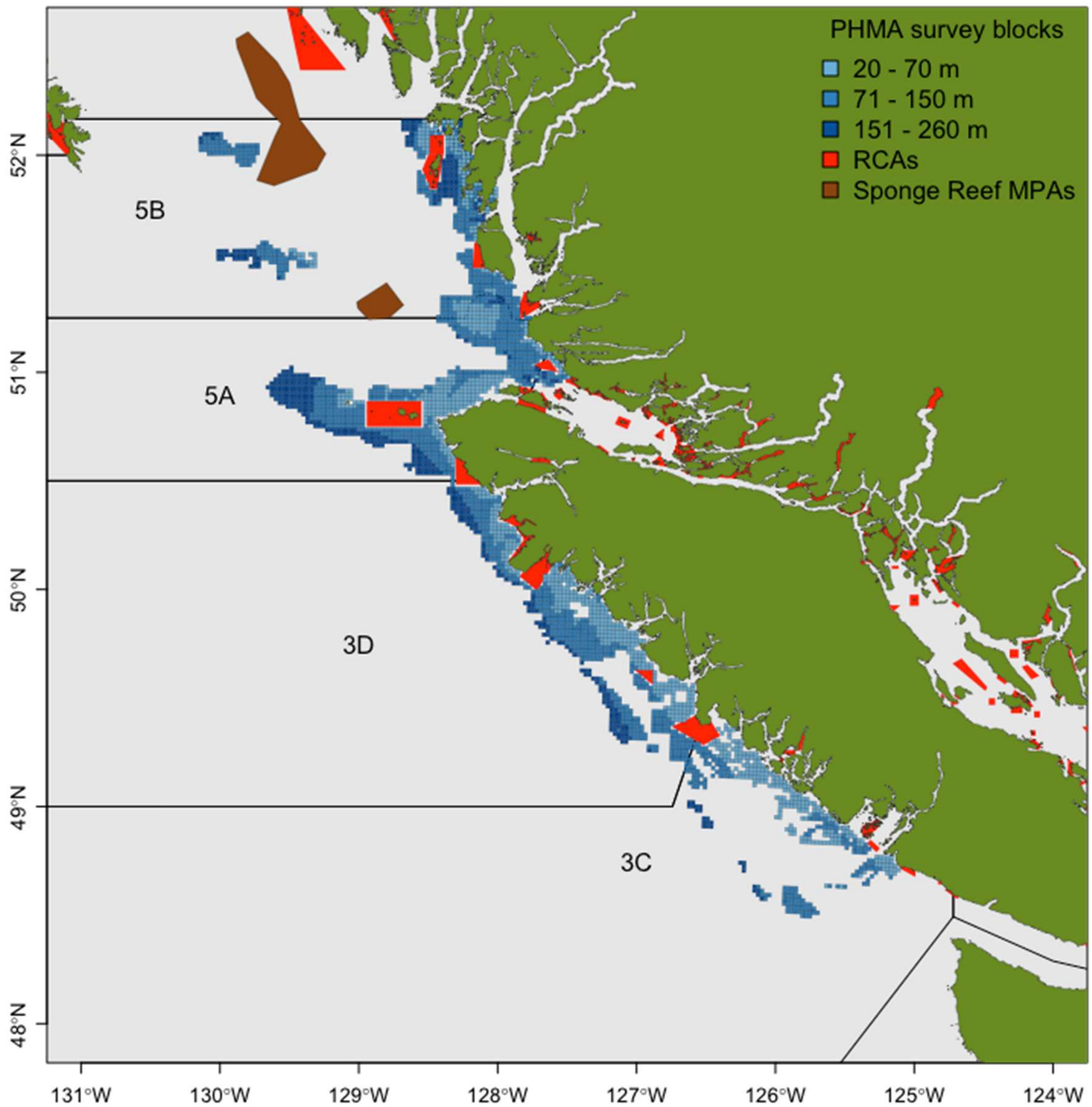

Figure 1.3. Map of 2 km x 2 km blocks for 3 depth strata for the PHMA survey grid in Southern BC.

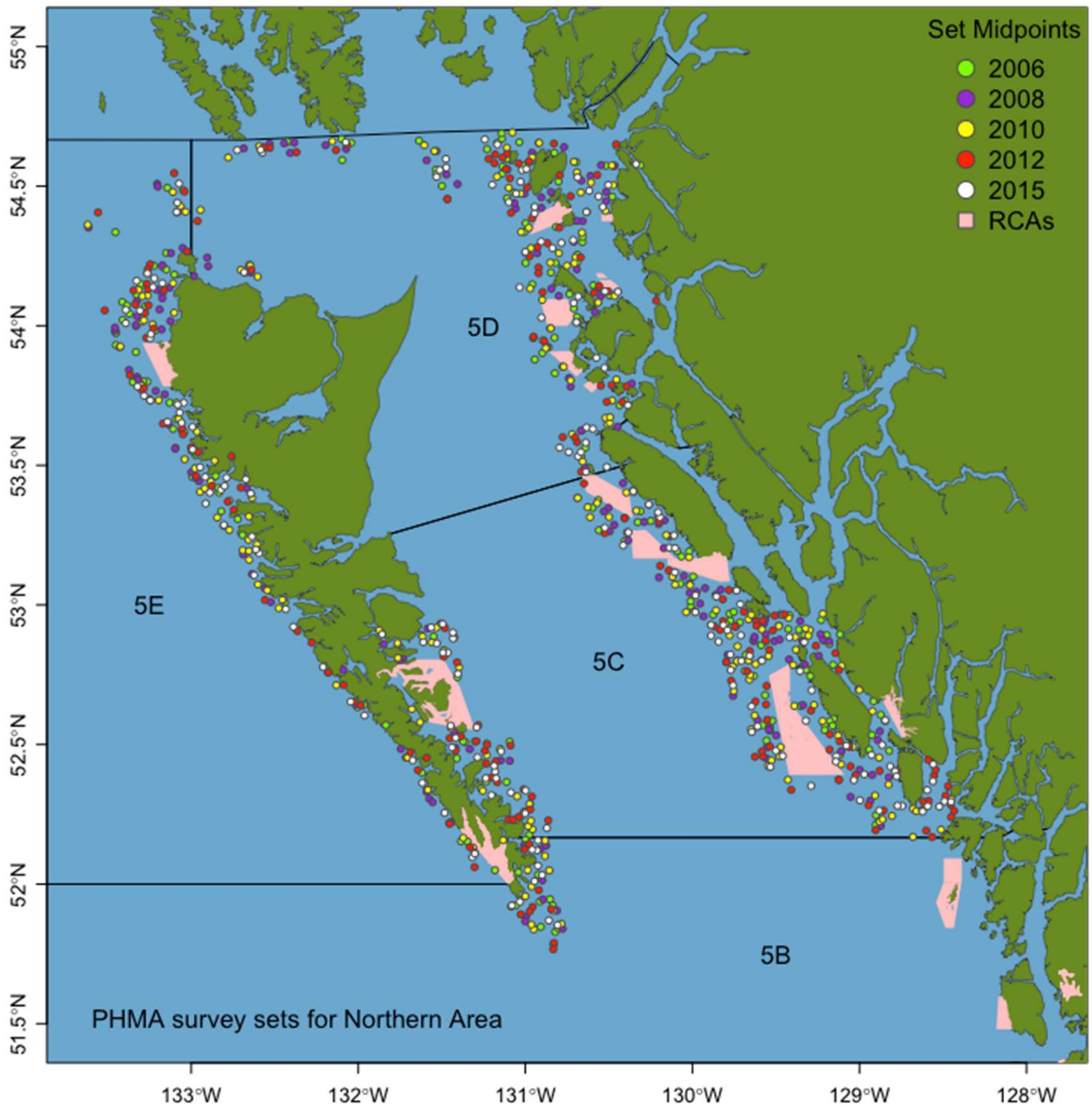

Figure 1.4. Set midpoints for all PHMA survey sets in Northern BC from 2006-2015.

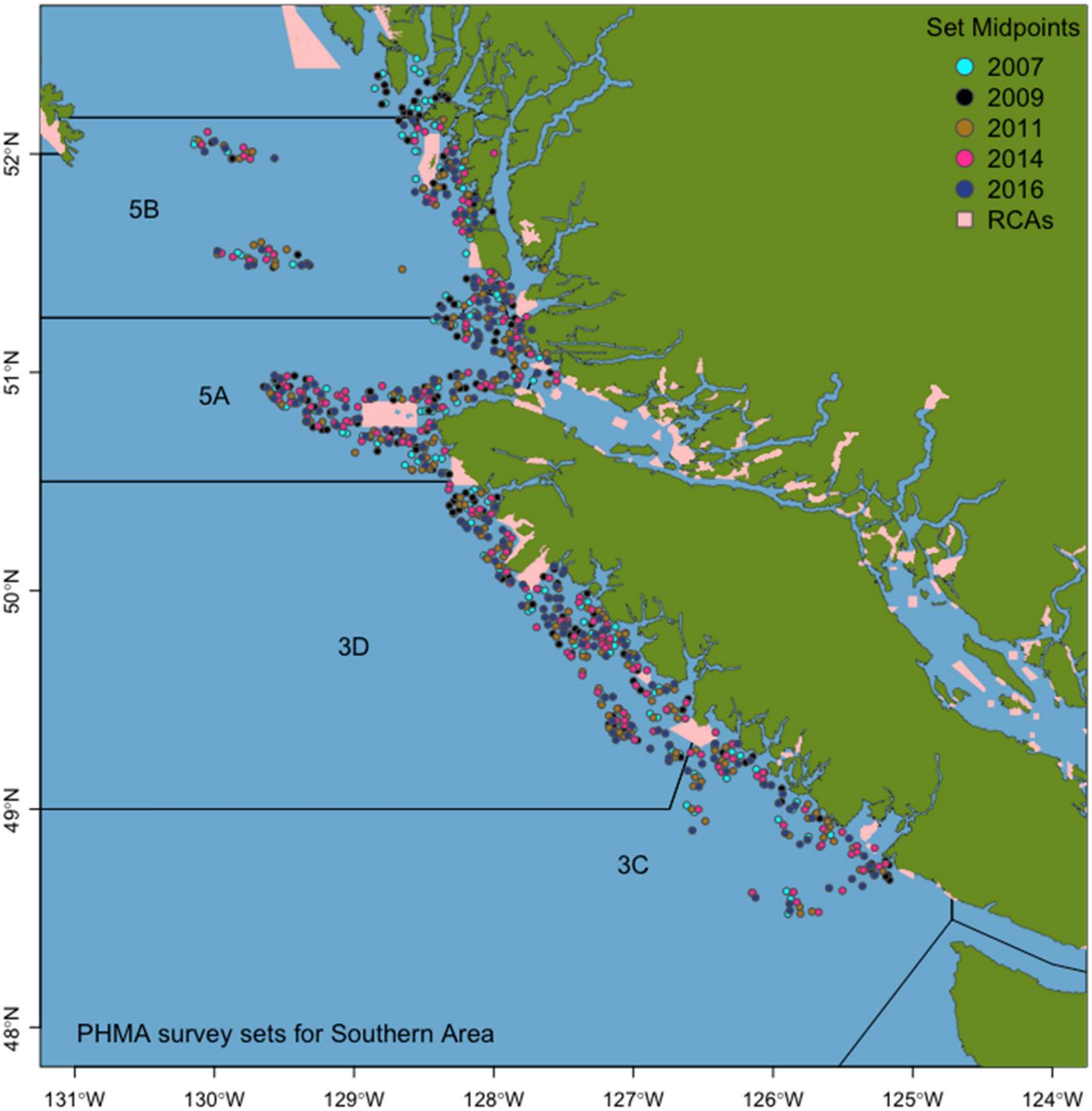

Figure 1.5. Set midpoints for all PHMA survey sets in Southern BC from 2007-2016.

FIGURES FOR PART 2 - SURVEY REVIEW

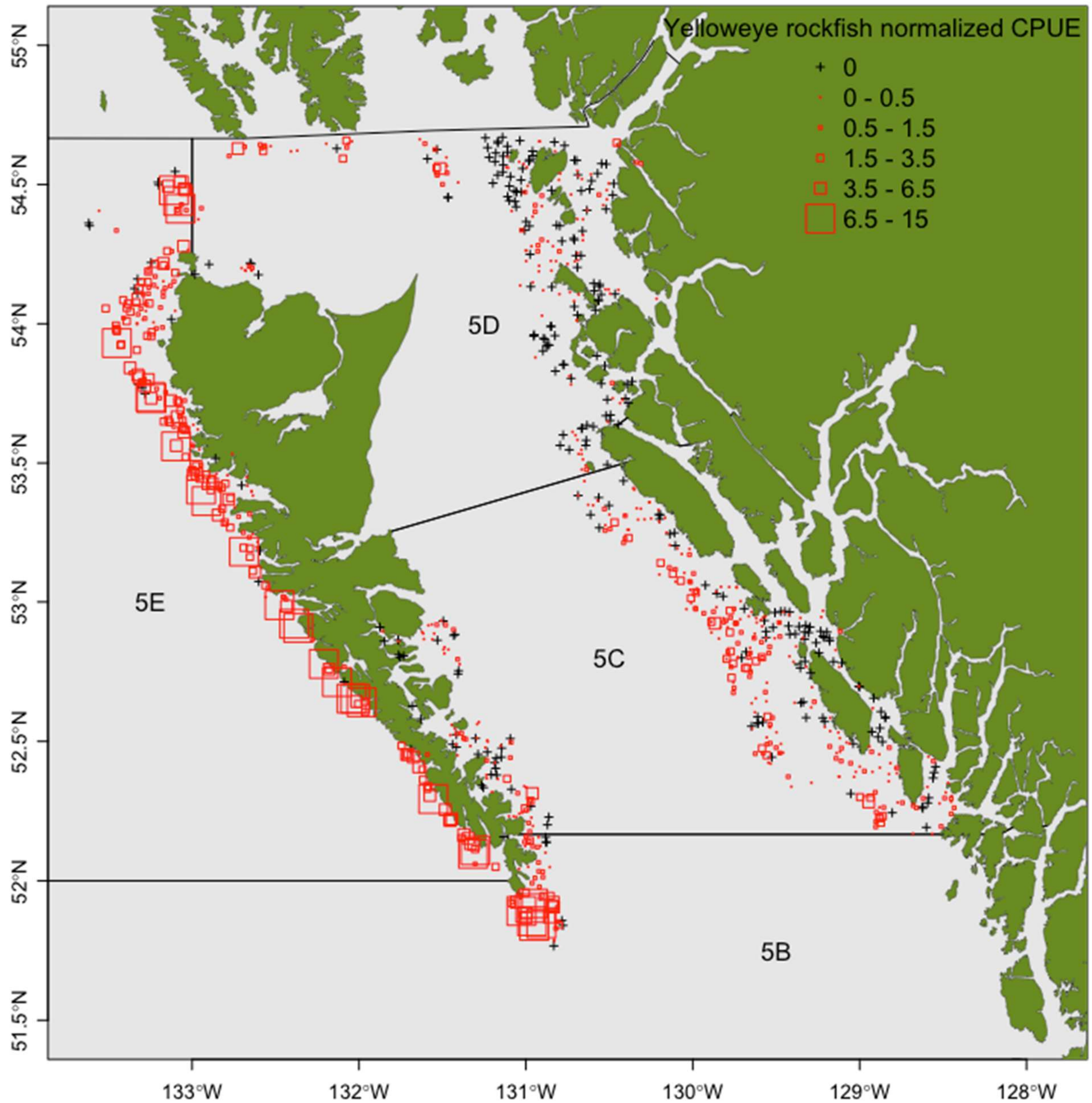

Figure 2.1. Distribution of normalized CPUE for Yelloweye Rockfish in Northern PHMA survey area for 2006-2015.

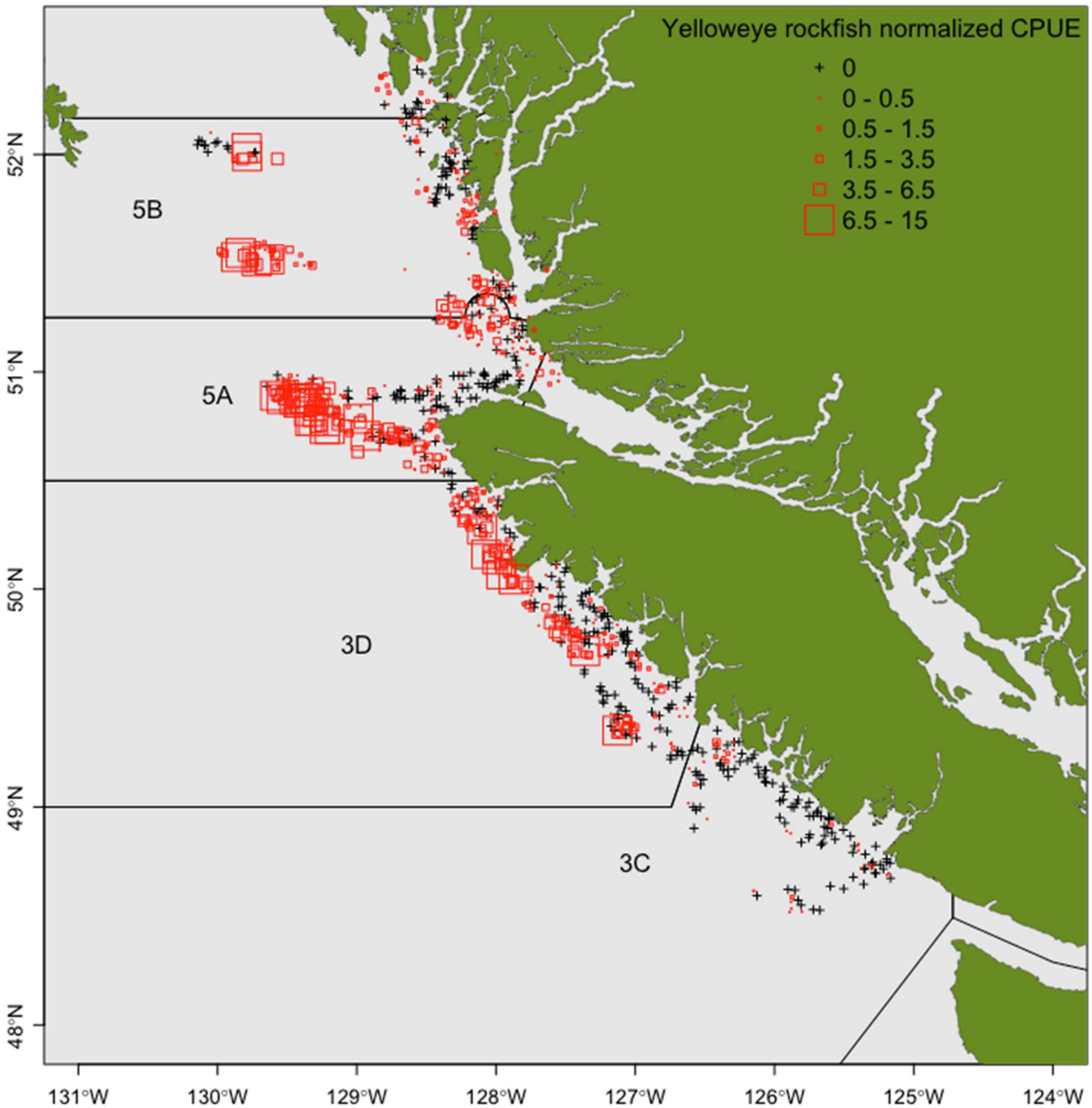

Figure 2.2. Distribution of normalized CPUE for Yelloweye Rockfish in Southern PHMA survey area for 2007-2016.

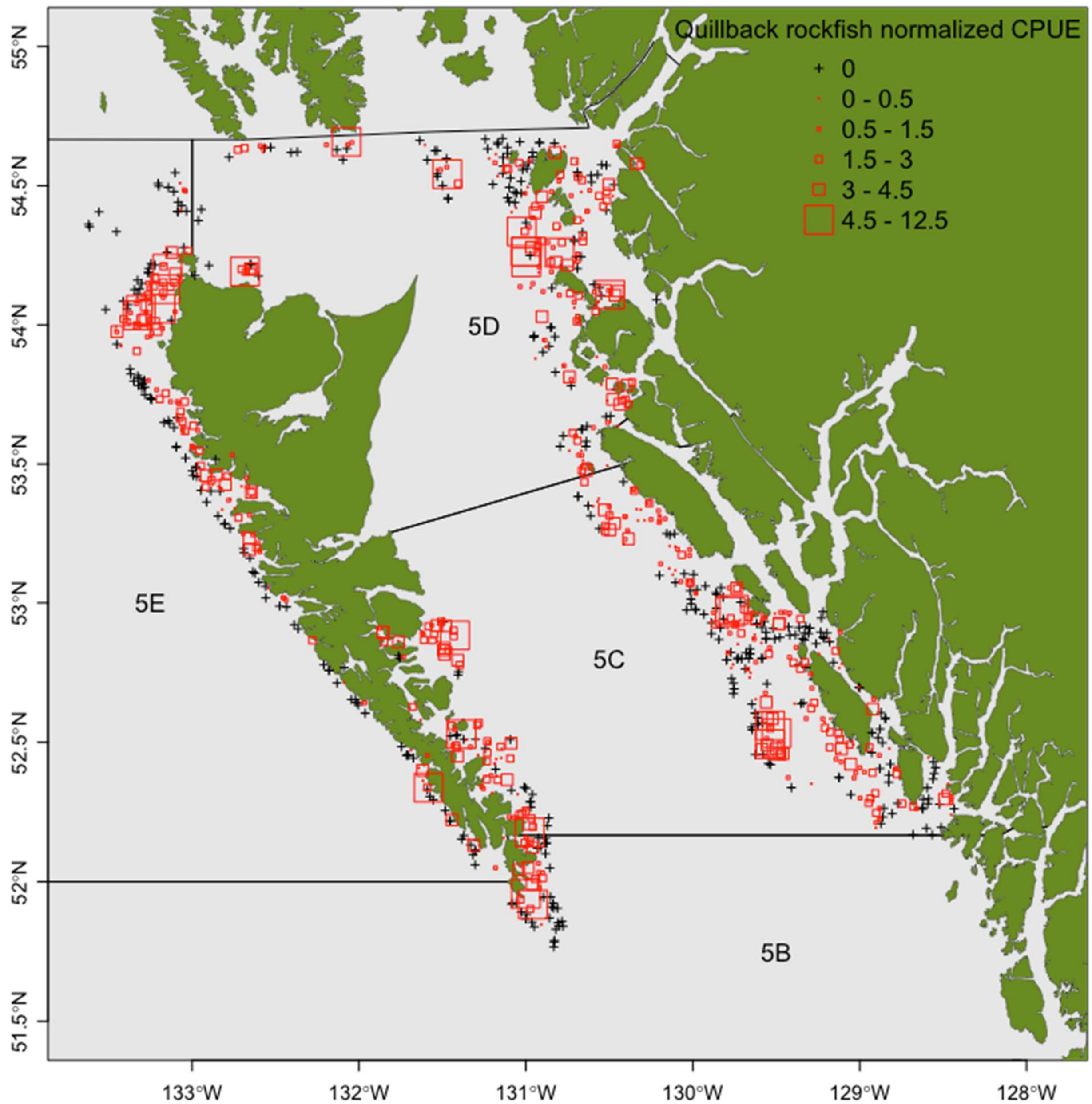

Figure 2.3. Distribution of normalized CPUE for Quillback Rockfish in Northern PHMA survey area for 2006-2015.

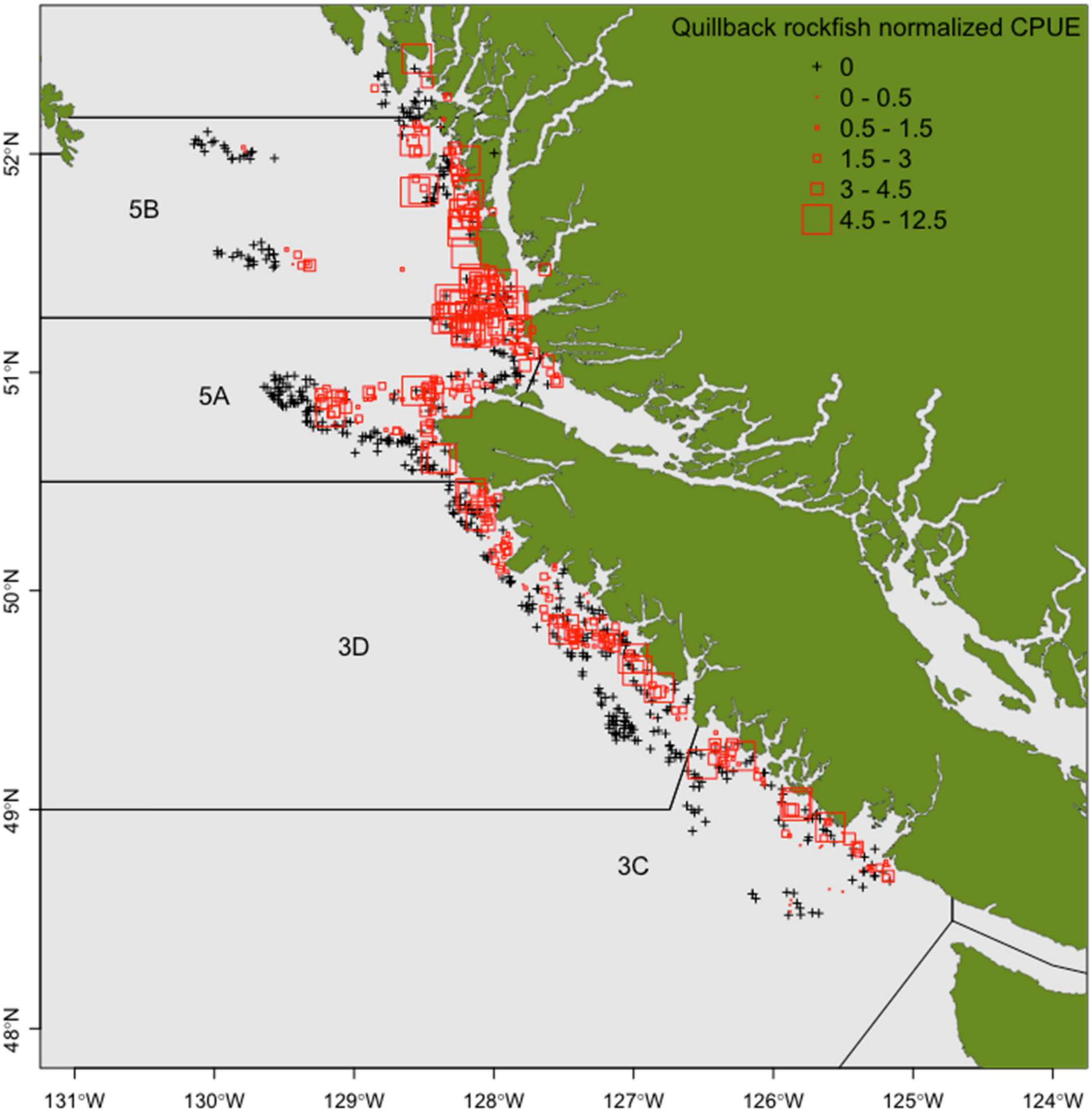

Figure 2.4. Distribution of normalized CPUE for Quillback Rockfish in Southern PHMA survey area for 2007-2016.

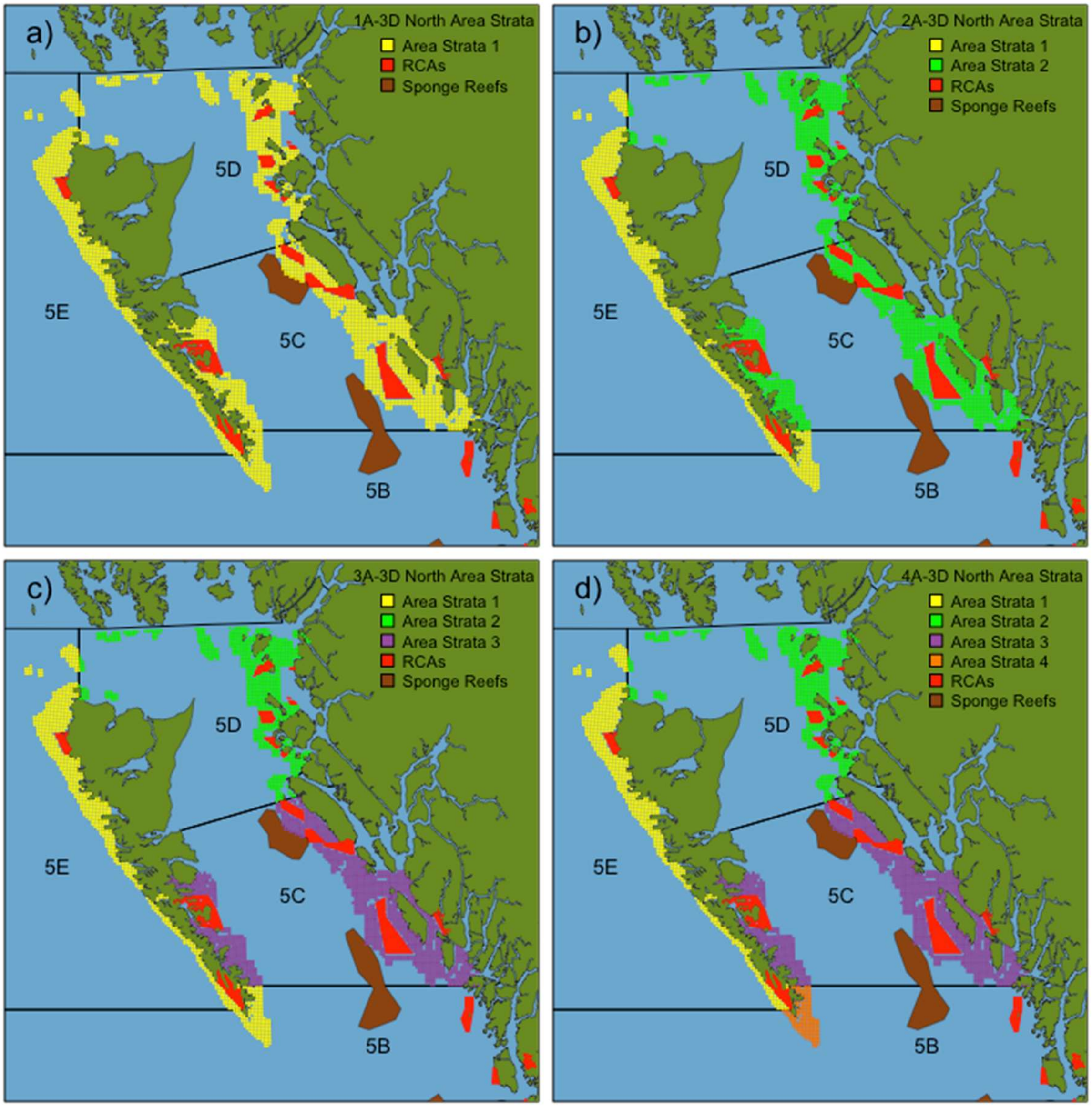

Figure 2.5. Different area stratification options for Northern PHMA survey area: a) 1 area stratum, b) 2 area strata, c) 3 area strata, and d) 4 area strata.

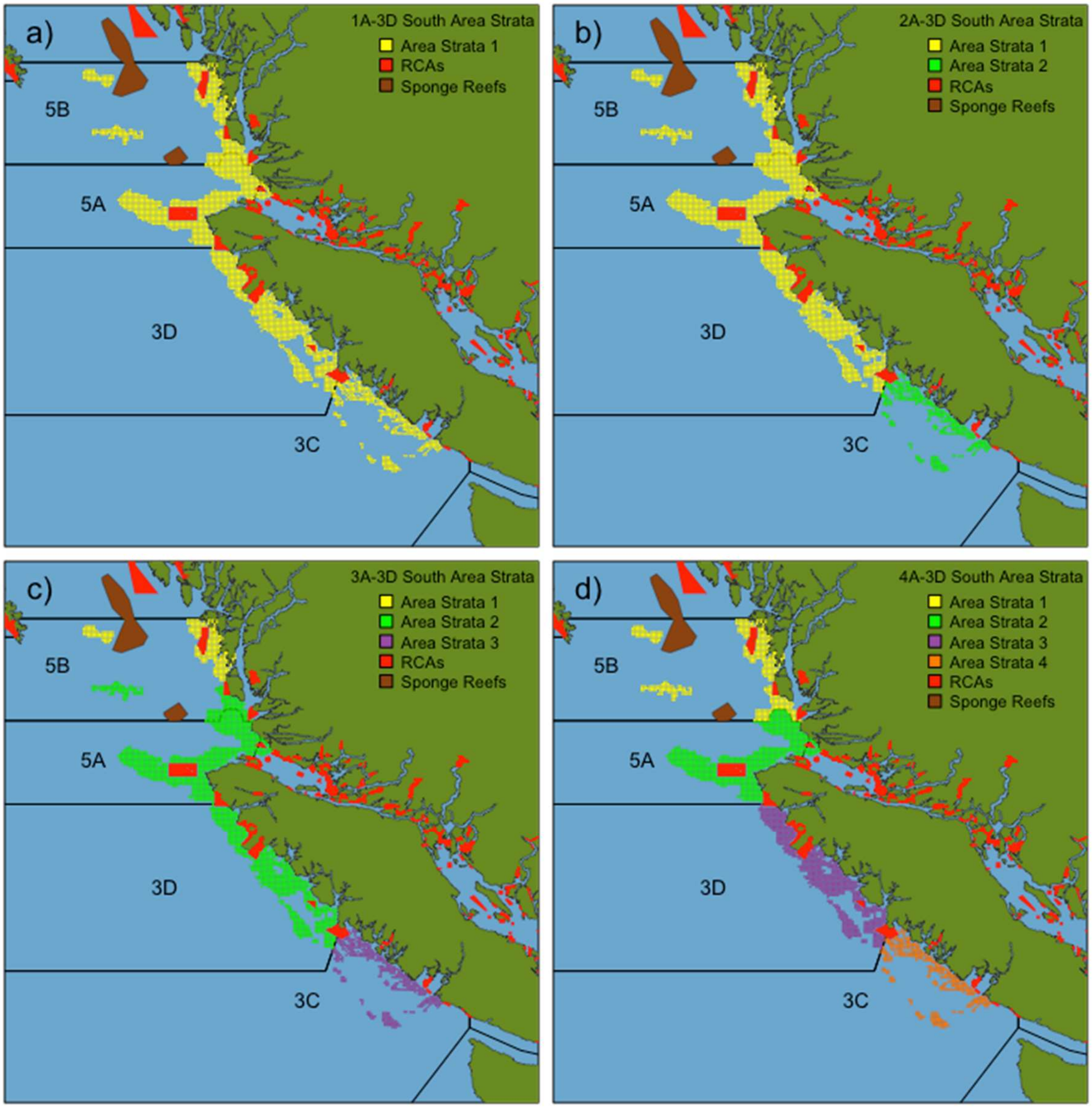

Figure 2.6. Different area stratification options for Southern PHMA survey area: a) 1 area stratum, b) 2 area strata, c) 3 area strata, and d) 4 area strata.

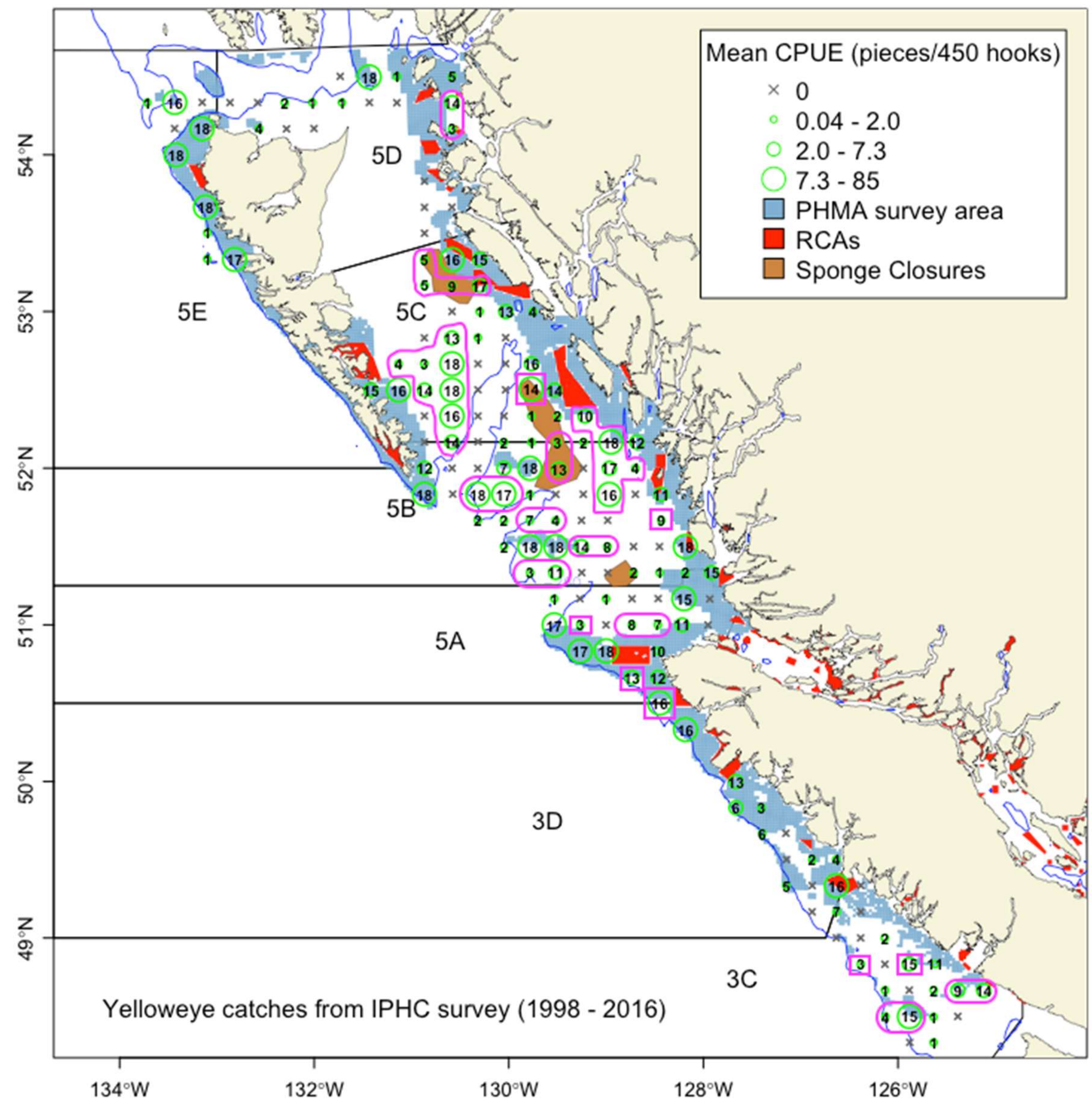

Figure 2.7. Mean annual Yelloweye CPUE for IPHC survey stations from 1998-2015. Numbers indicate number of years where stations had at least 1 Yelloweye observed in data. Blue line indicates contour for 260 m depth. Pink polygons highlight areas with Yelloweye catch in at least 3 years that are not covered by the PHMA survey.

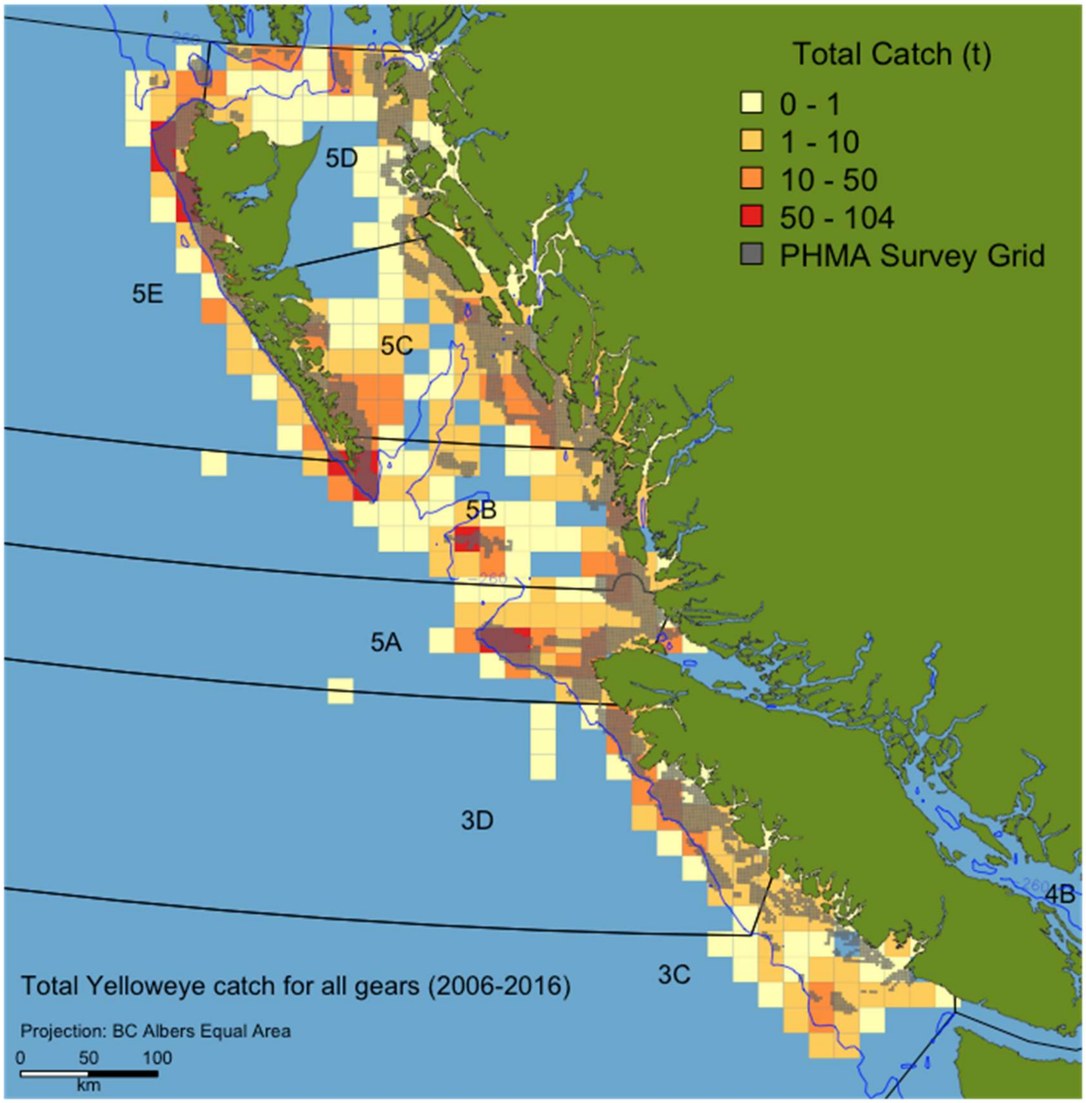

Figure 2.8. Distribution of total Yelloweye Rockfish catches from commercial trap and hook and line fisheries from 2006-2016 by 18.5 km x 18.5 km blocks in outside management unit. PHMA survey blocks are overlaid to compare survey area with historical occurrence data for Yelloweye. Blue line indicates contour for 260 m depth. Grid cells with catches from < 3 vessels are excluded due to privacy restrictions with commercial fisheries data.

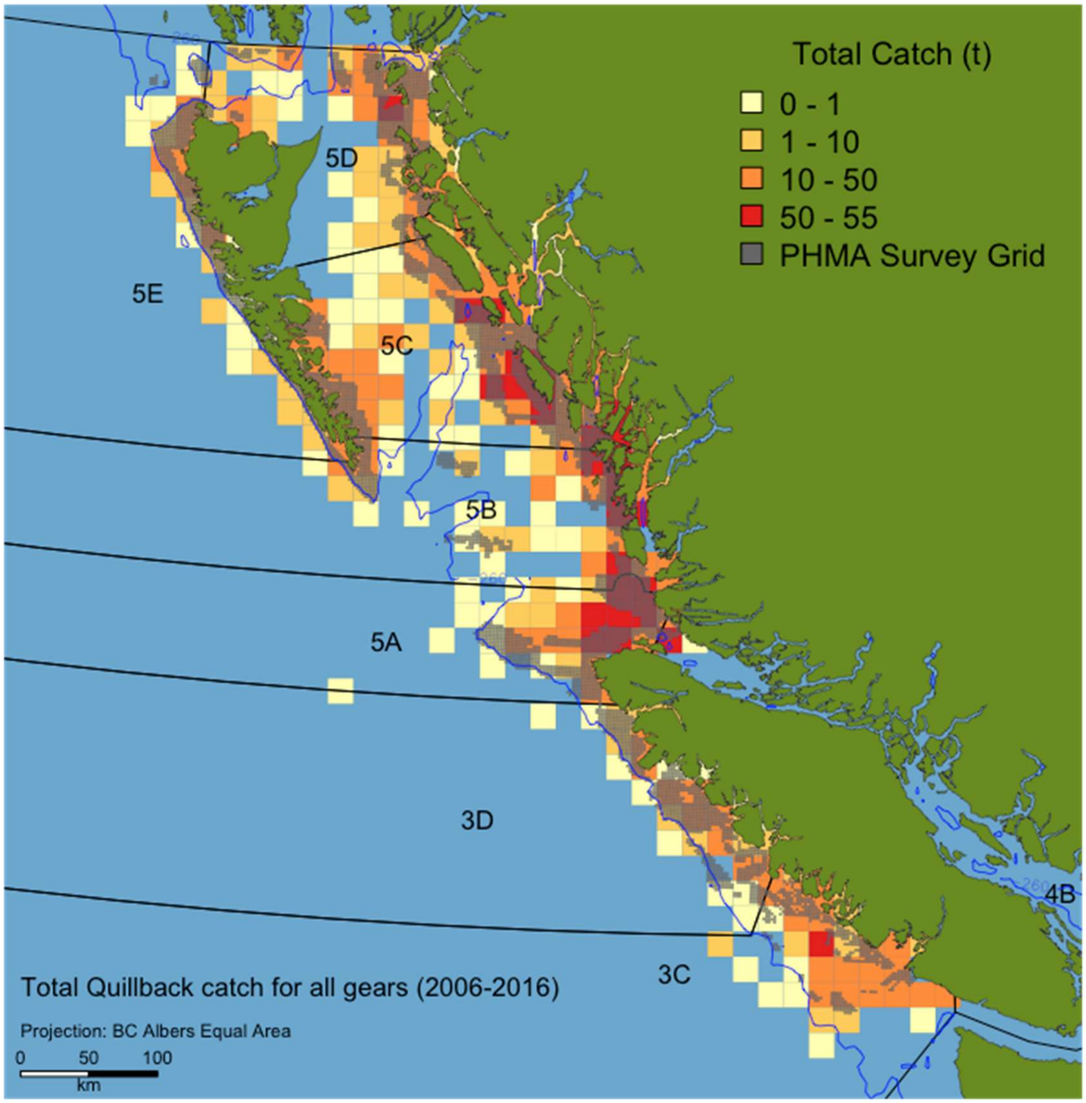

Figure 2.9. Distribution of total Quillback Rockfish catches from commercial trap and hook and line fisheries from 2006-2016 by 18.5 km x 18.5 km blocks in outside management unit. PHMA survey blocks are overlaid to compare survey area with historical occurrence data for Quillback. Blue line indicates contour for 260 m depth. Grid cells with catches from < 3 vessels are excluded due to privacy restrictions with commercial fisheries data.

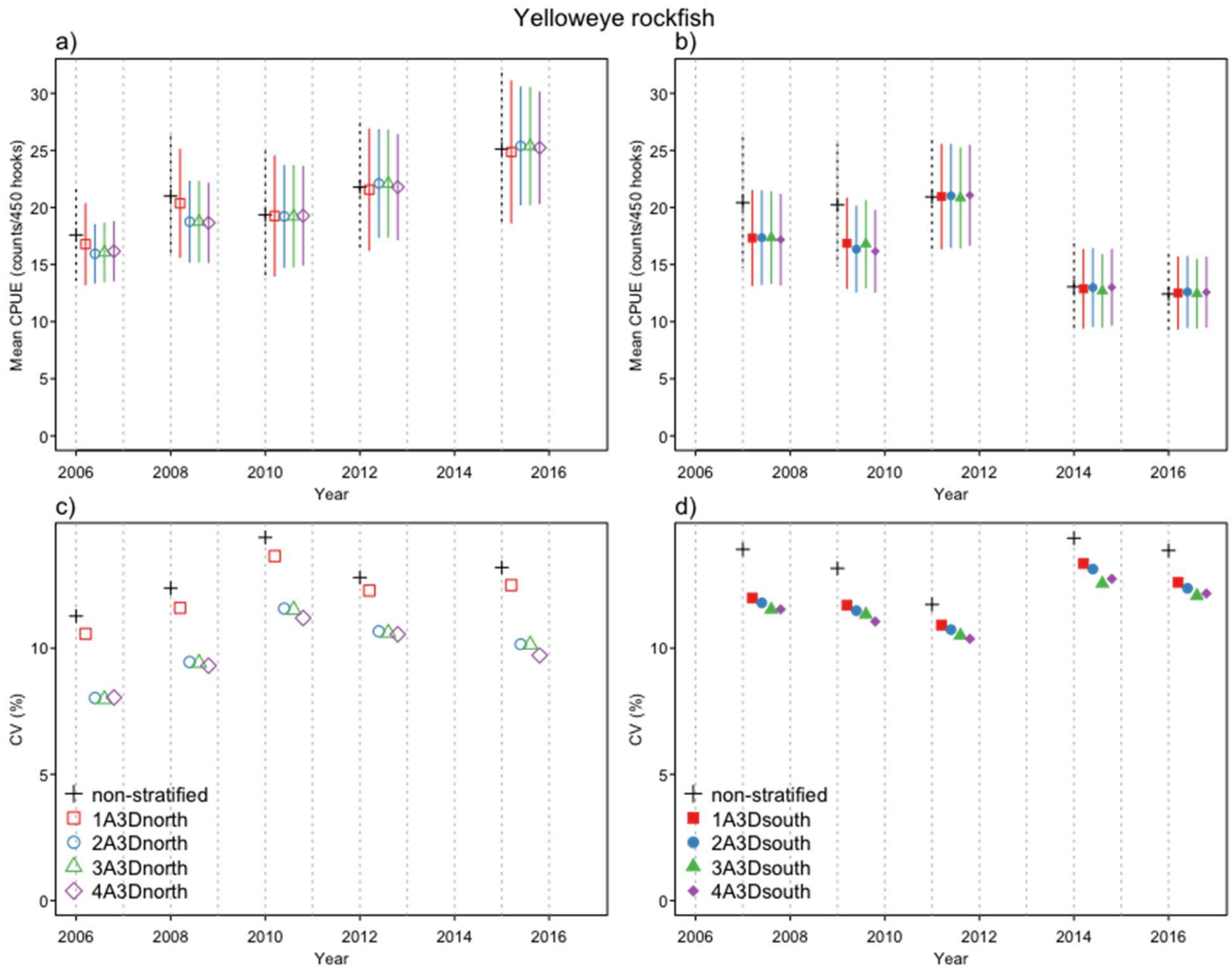

Figure 2.10. Annual stratified and non-stratified mean CPUE (counts/450 hooks) and CVs (%) for Yelloweye Rockfish for different stratification options for Northern (open points in a and c) and Southern survey areas (closed points in b and d). Values for different stratifications are jittered so that overlapping data points are visible.

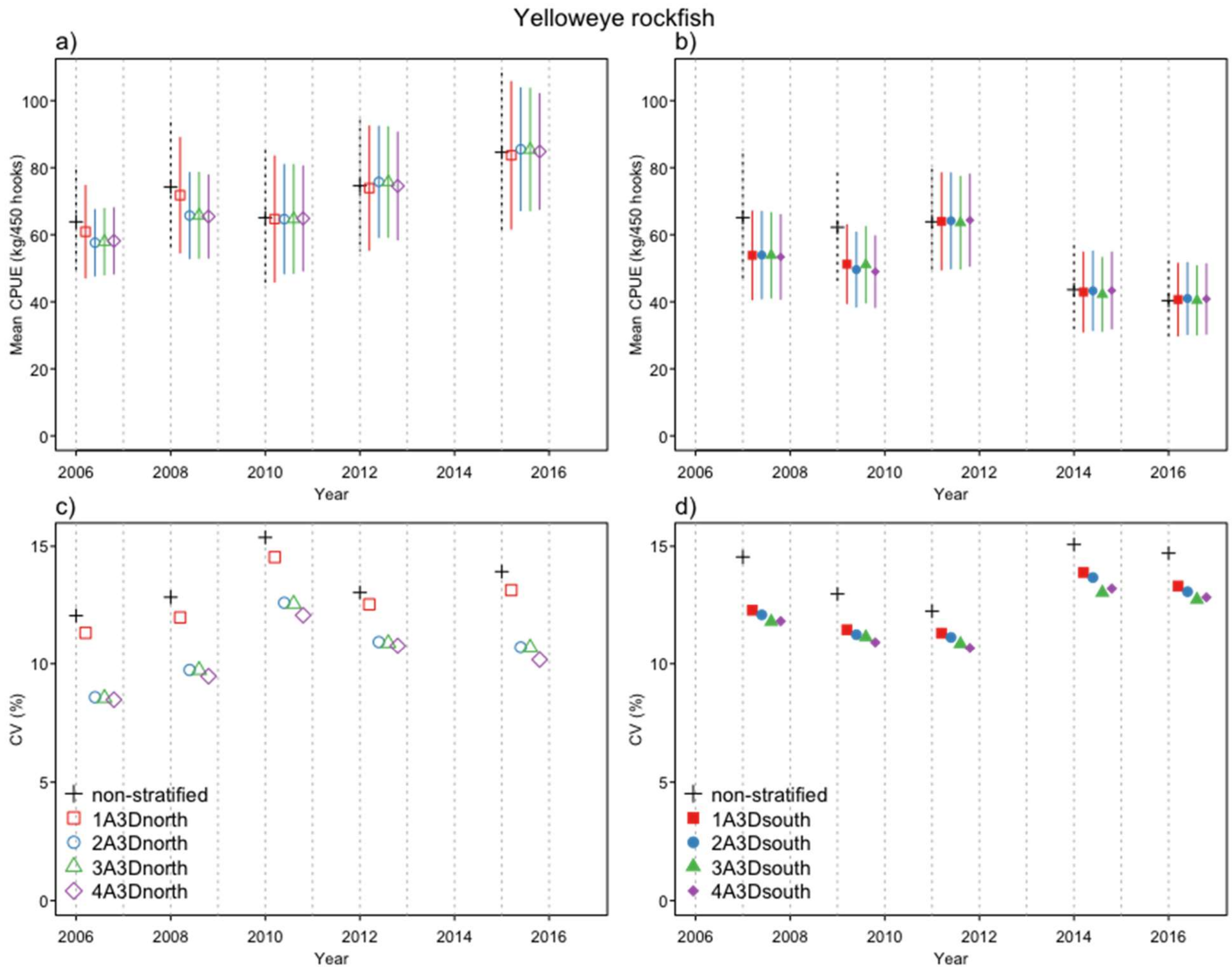

Figure 2.11. Annual stratified and non-stratified mean CPUE (counts/450 hooks) and CVs (%) for Yelloweye Rockfish for different stratification options for Northern (open points in a and c) and Southern survey areas (closed points in b and d). Values for different stratifications are jittered so that overlapping data points are visible.

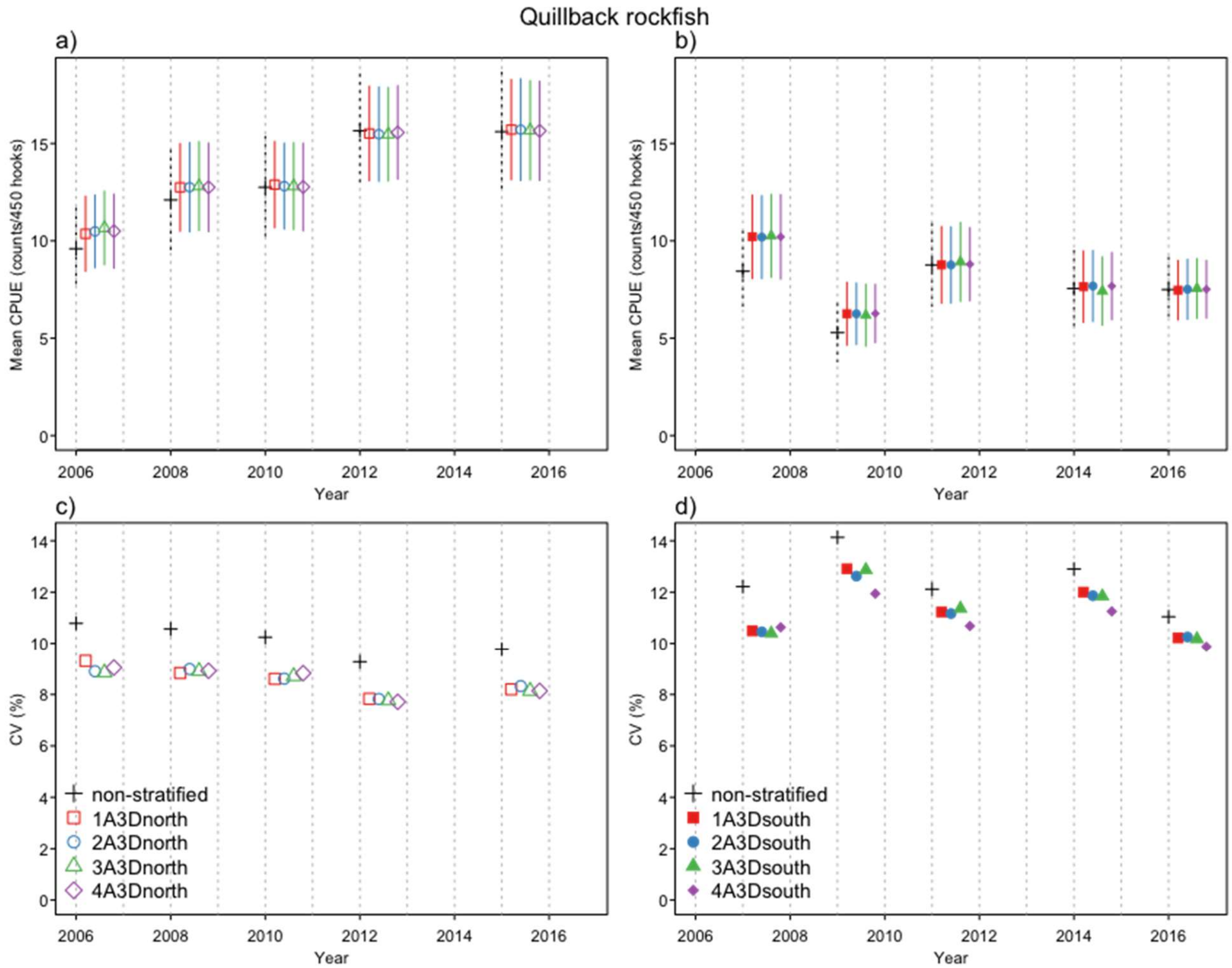

Figure 2.12. Annual stratified and non-stratified mean CPUE (counts/450 hooks) and CVs (%) for Quillback Rockfish for different stratification options for Northern (open points in a and c) and Southern survey areas (closed points in b and d). Values for different stratifications are jittered so that overlapping data points are visible.

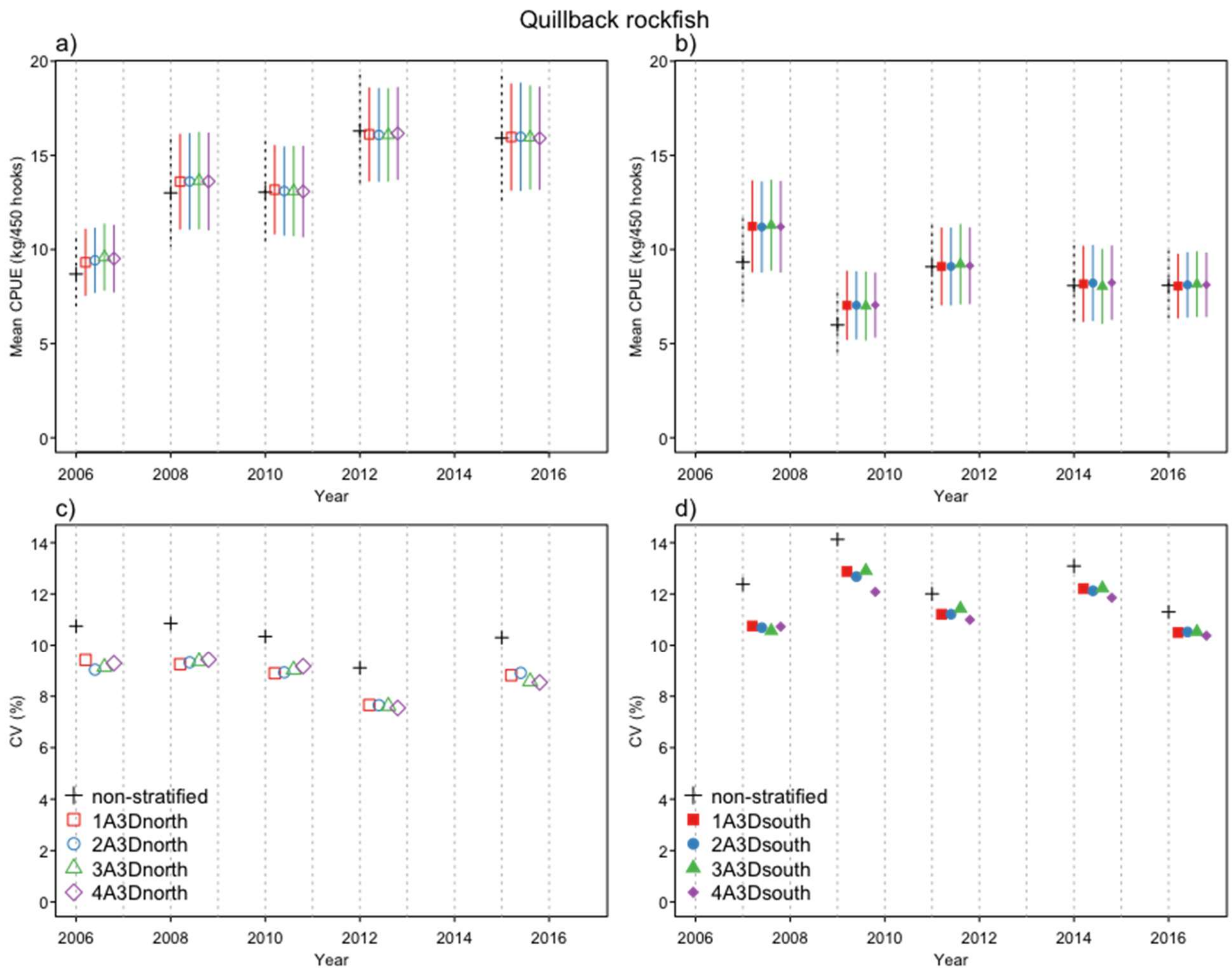

Figure 2.13. Annual stratified and non-stratified mean CPUE (counts/450 hooks) and CVs (%) for Quillback Rockfish for different stratification options for Northern (open points in a and c) and Southern survey areas (closed points in b and d). Values for different stratifications are jittered so that overlapping data points are visible.

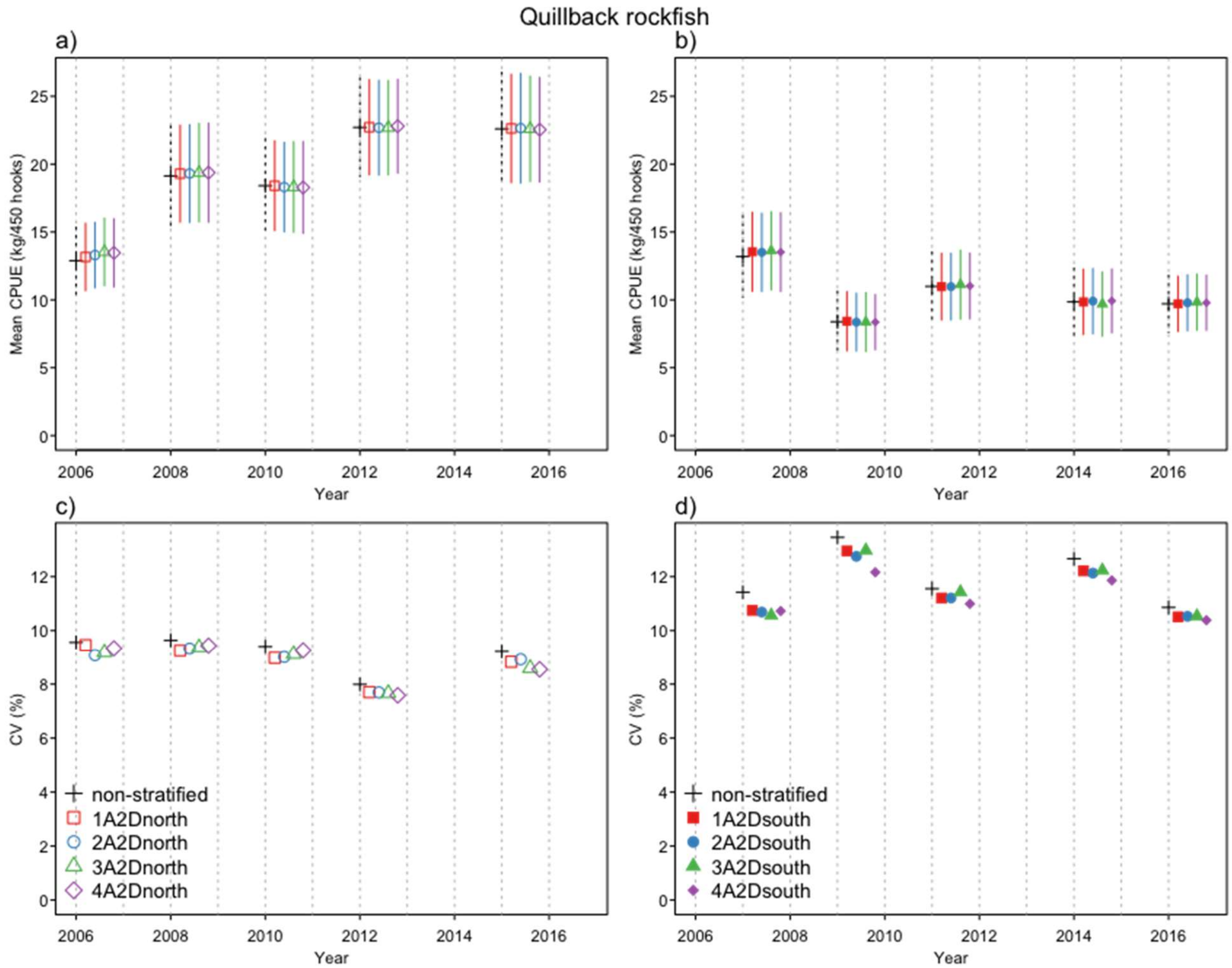

Figure 2.14. Annual stratified and non-stratified mean CPUE (counts/450 hooks) and CVs (%) for Quillback Rockfish for different stratification options with only 2 depth strata (20-70 m, 71-150 m) for Northern (open points in a and c) and Southern survey areas (closed points in b and d). Values for different stratifications are jittered so that overlapping data points are visible. Sets from depths > 150 m were excluded.

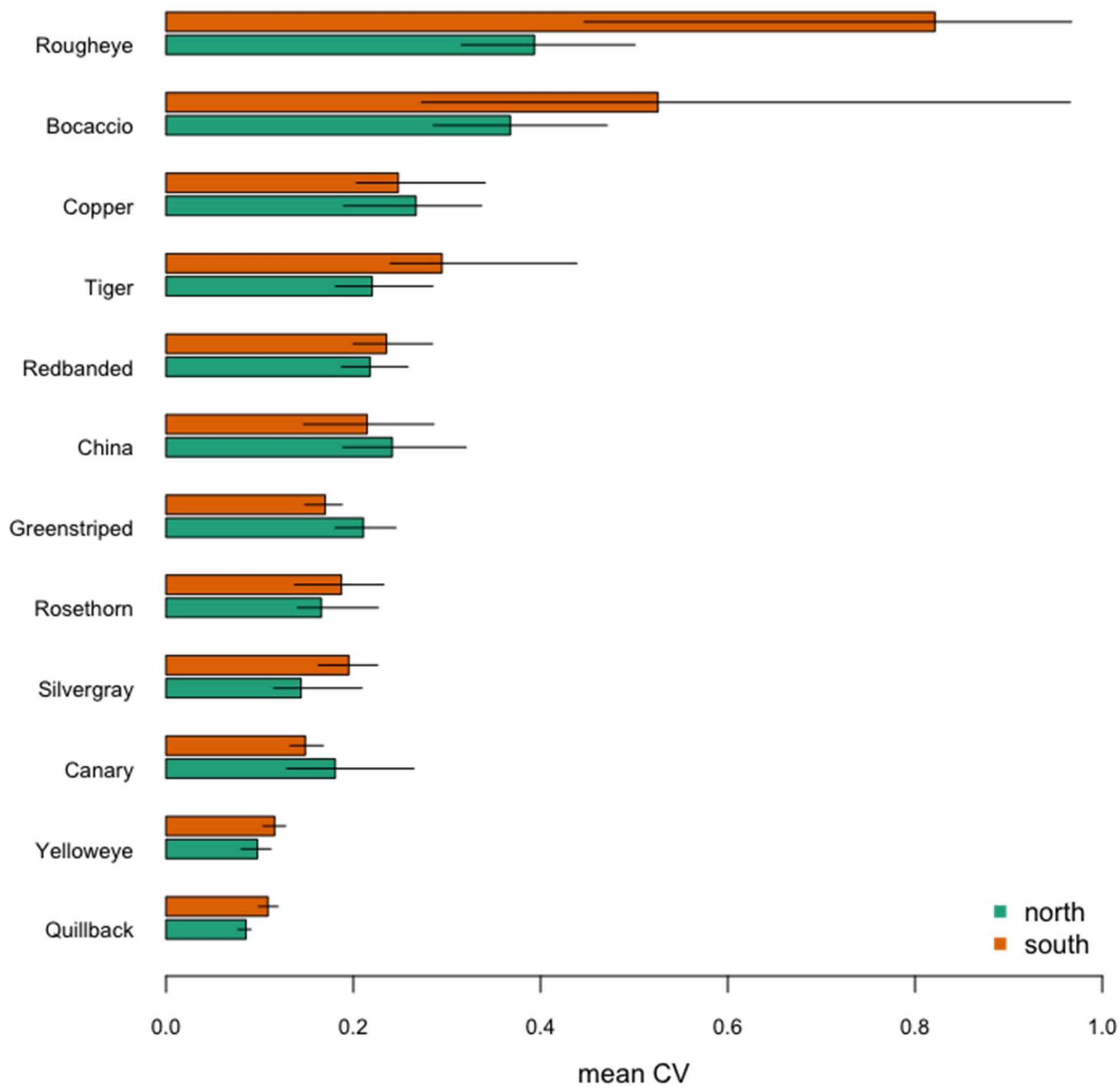

Figure 2.15. Mean CVs for stratified mean CPUE under 4A-3D stratification for PHMA survey areas for different rockfish species. Black horizontal lines on bars indicate the minimum and maximum annual CVs from the 2006-2016 survey data.

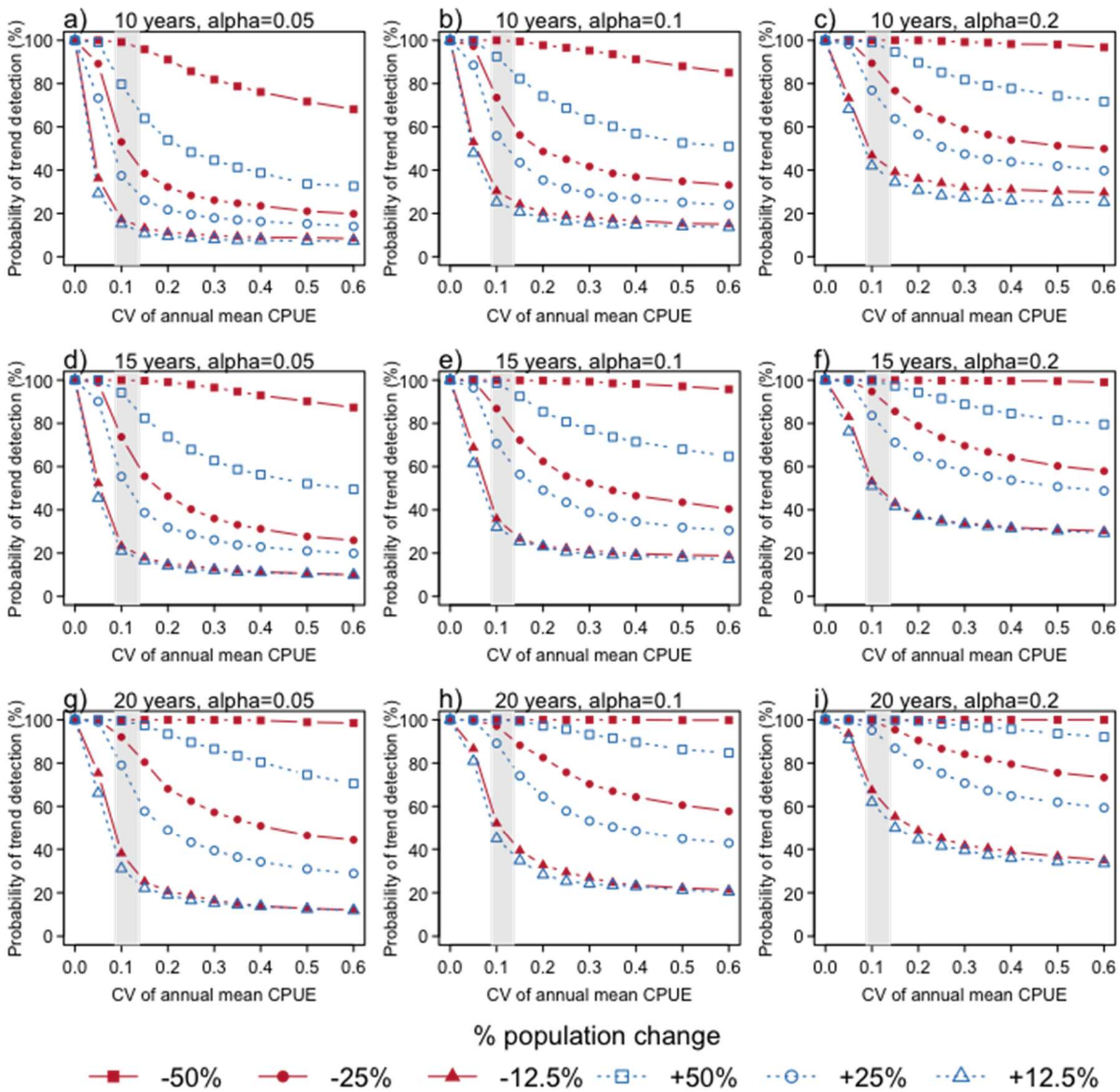

Figure 2.16. Power analyses for detecting population changes of +/- 10%, 25%, and 50% over 10 (a,b,c), 15(d,e,f), or 20(g,h,i) year periods under different CVs. The power analyses are based on 1000 simulations using biennial sampling and reflect the probability of correctly detecting a trend in the North or the South, when one exists. Simulations were conducted with alpha levels of 0.05 (a,d,g), 0.10 (b,e,h), and 0.20 (c,f,i). Grey shaded areas indicate the range of CVs observed in the PHMA survey for Yelloweye and Quillback.

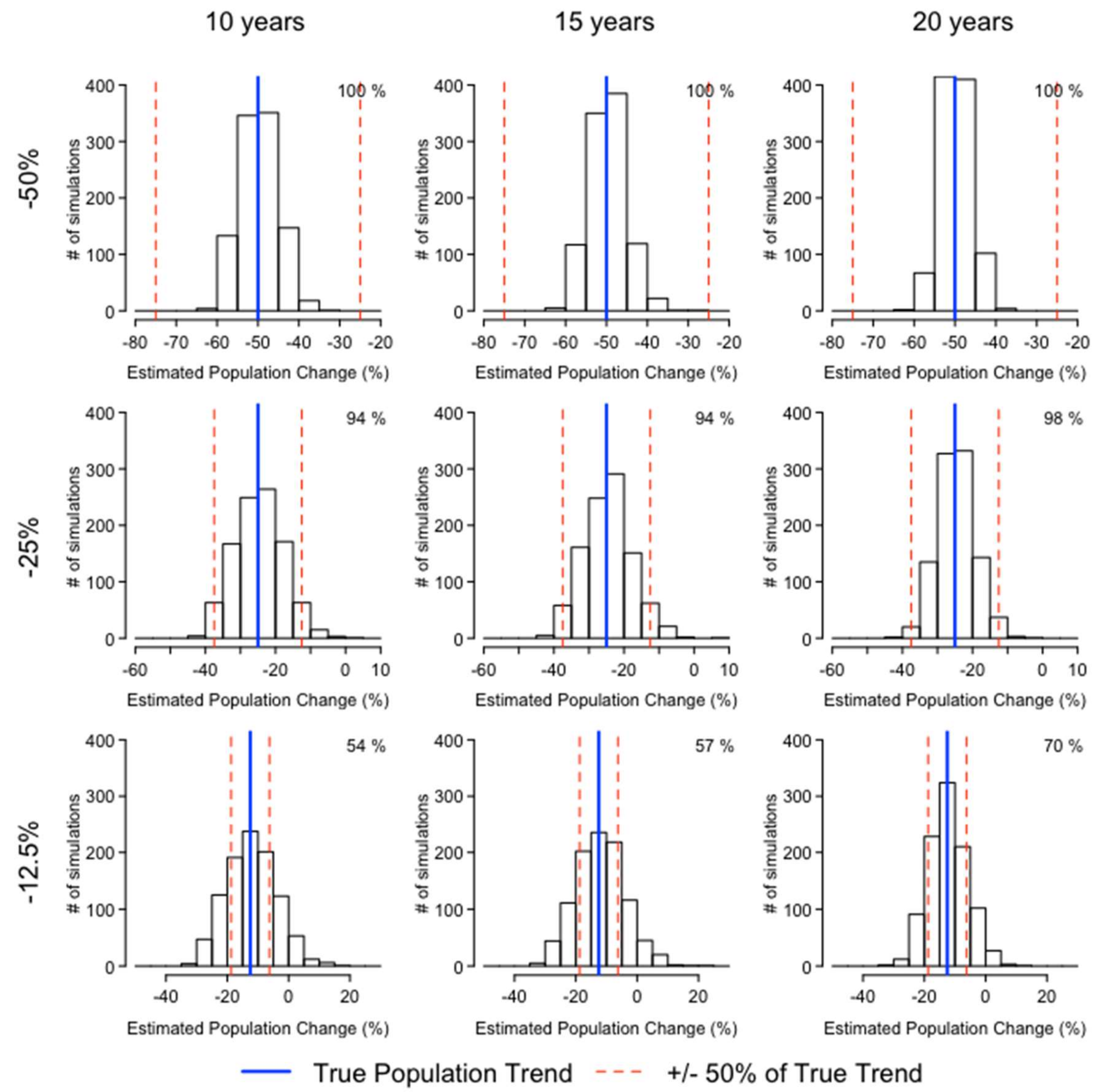

Figure 2.17. Estimated change in population from 1000 simulations with 10% CV for population decreases of 50%, 25%, and 12.5% over 10, 15, and 20 years, based on 196 samples every 2 years. Percentage in top right corner of plots indicates the proportion of simulations with estimated trends that were within 50% of the true trend.

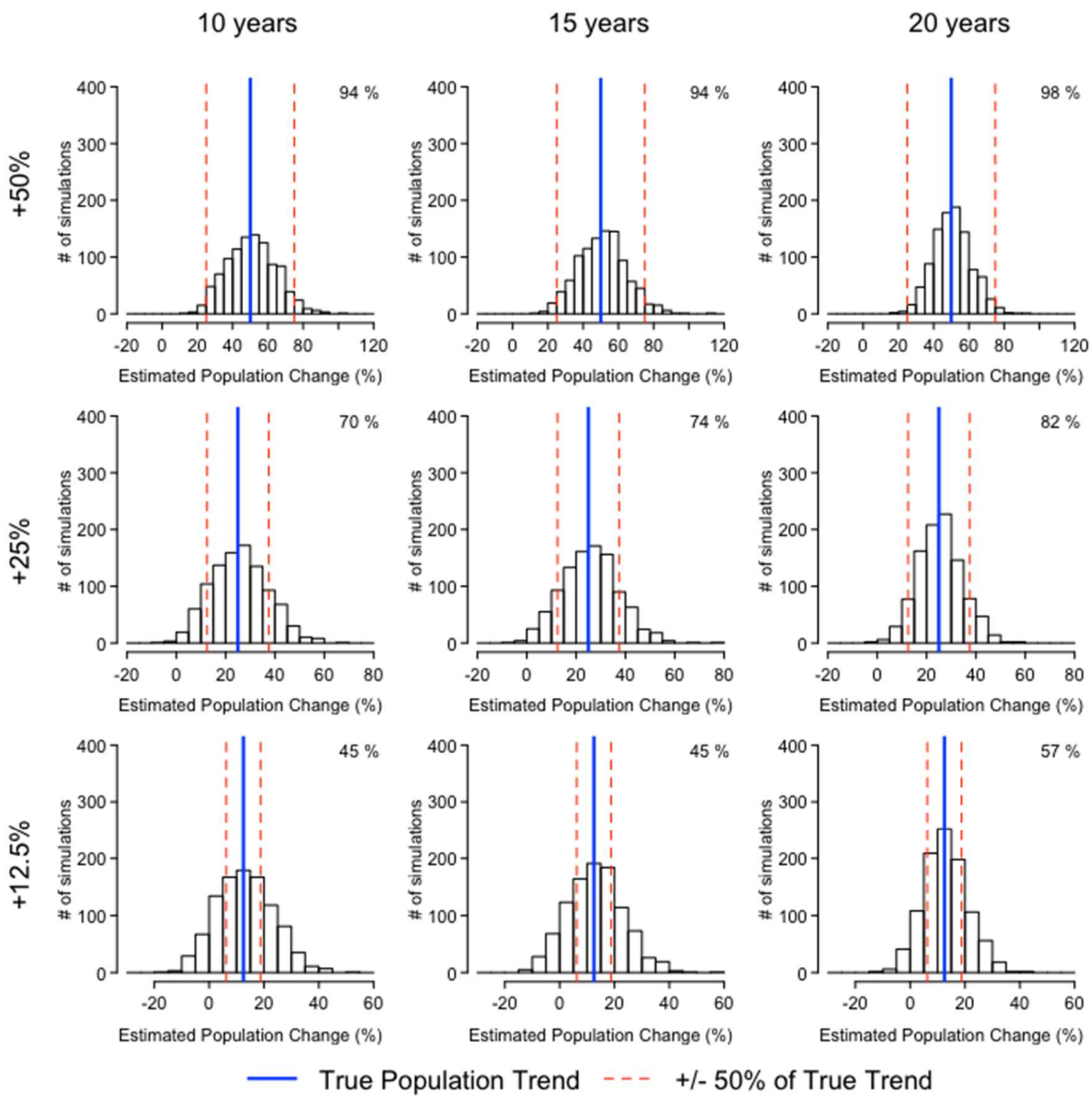

Figure 2.18. Estimated change in population from 1000 simulations with 10% CV for population increases of 50%, 25%, and 12.5% over 10, 15, and 20 years, based on 196 samples every 2 years. Percentage in top right corner of plots indicates the proportion of simulations with estimated trends that were within 50% of the true trend.

APPENDIX A - YELLOWEYE DATA SUMMARY FIGURES

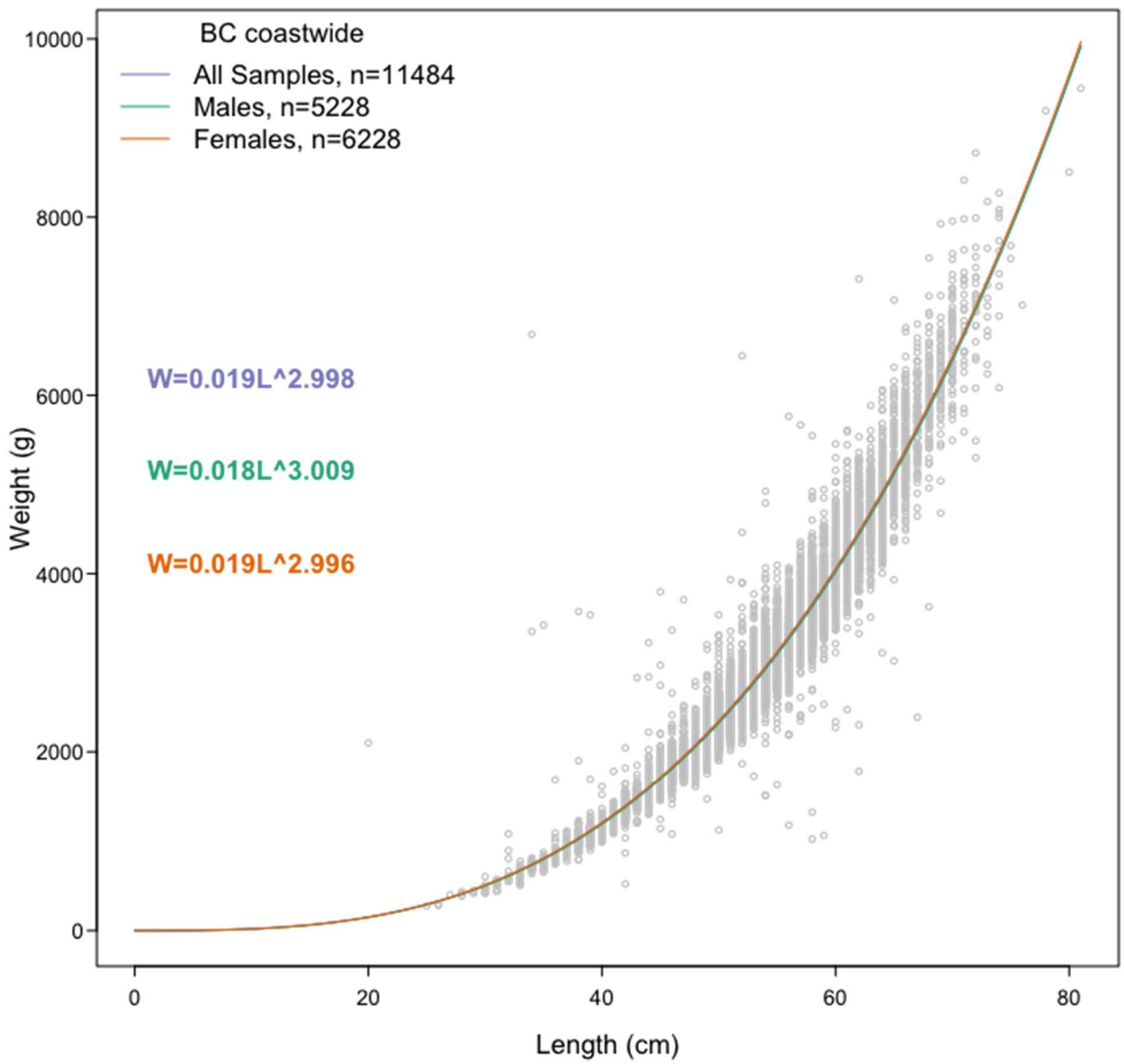

Figure A.1. Length-weight relationship for Yelloweye Rockfish for all PHMA survey sets with weight and fork length data from 2009-2016.

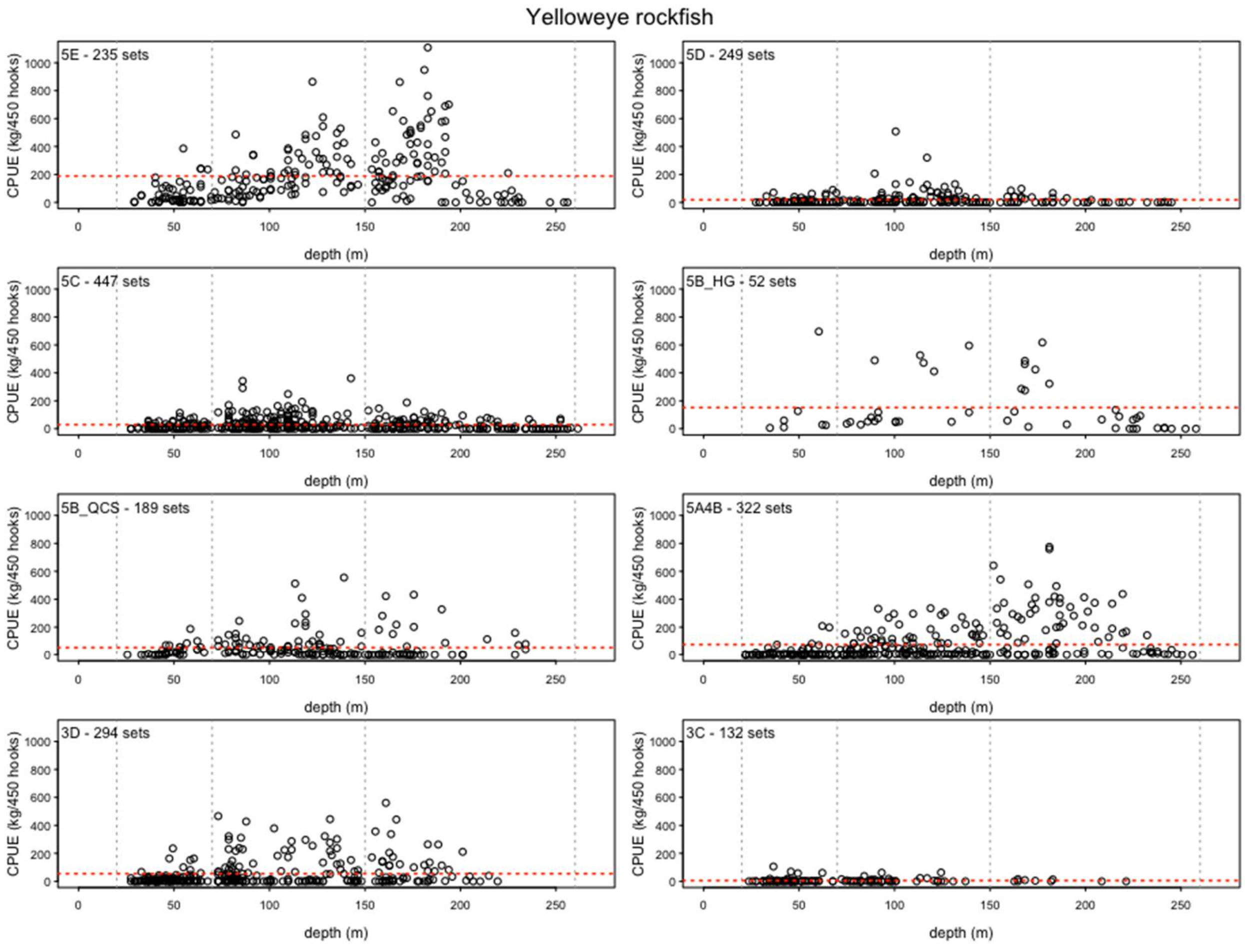

Figure A.2. CPUE (kg/450 hooks) by depth for Yelloweye Rockfish for PHMA survey sets from 2006-2016 for different management areas. Dotted vertical lines indicate depth strata boundaries and dotted red lines indicate the mean.

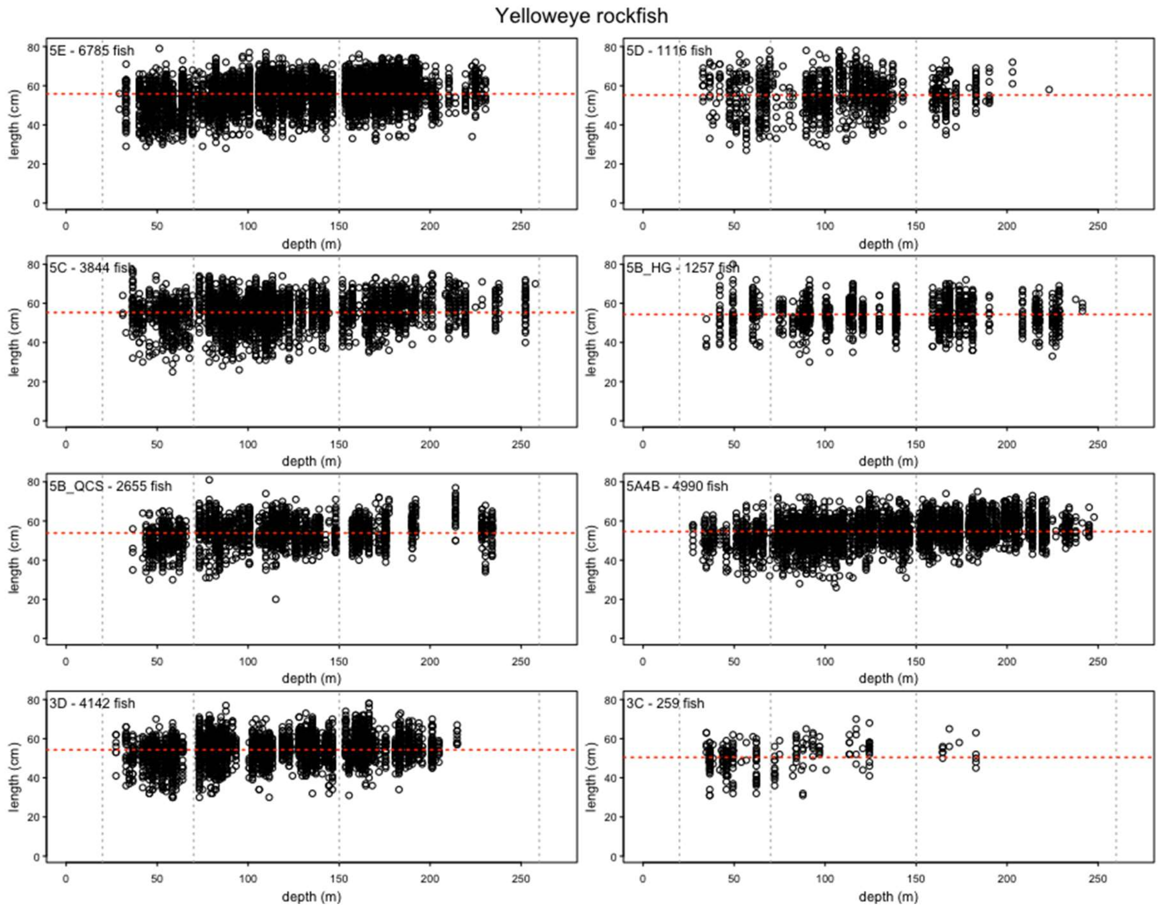

Figure A.3. All length data for Yelloweye Rockfish by depths for different management areas for all PHMA survey sets from 2006-2016. Dotted vertical lines indicate depth strata boundaries and dotted red lines indicate the mean.

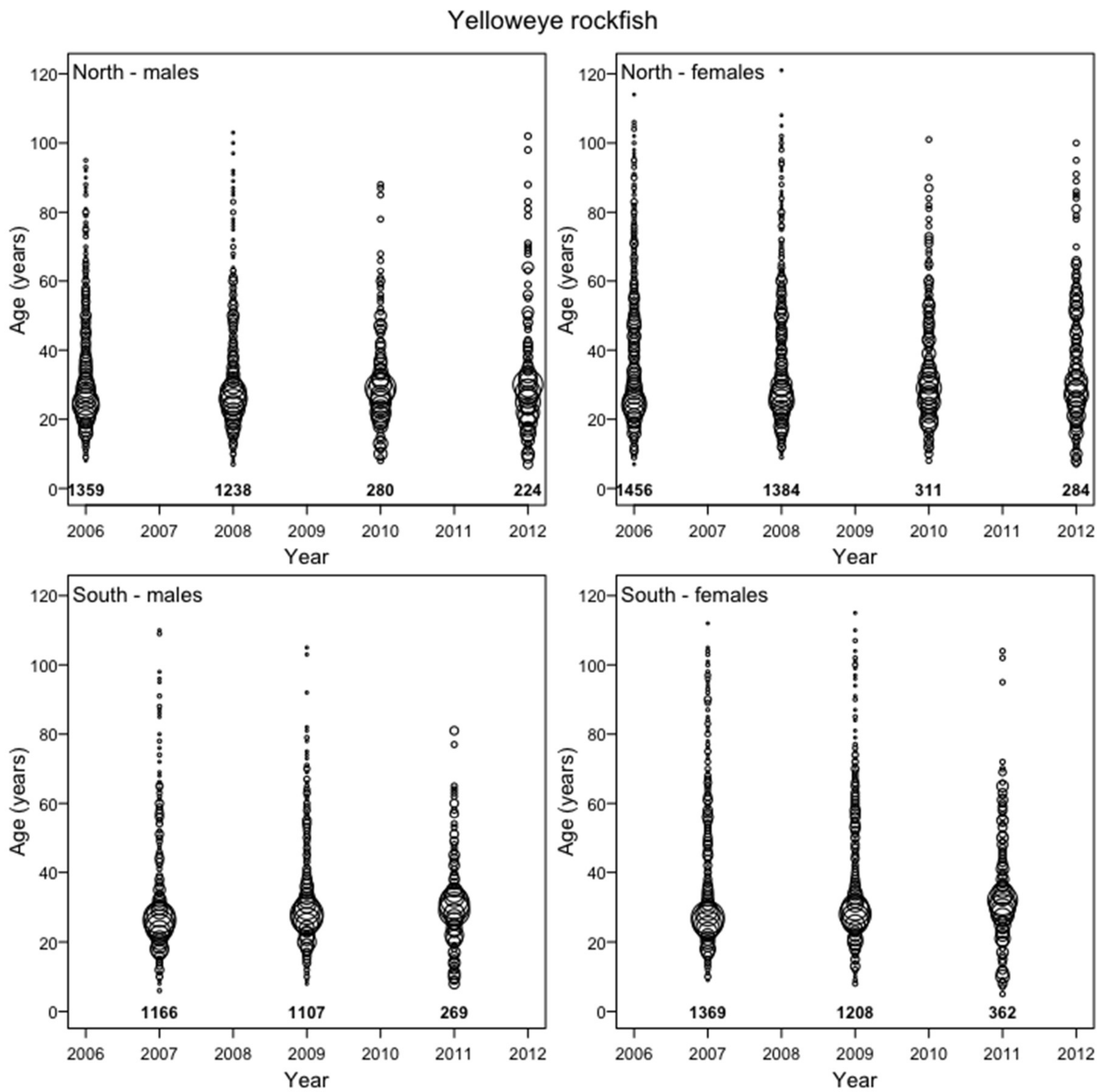

Figure A.4. Yelloweye Rockfish ages by sex, year, and survey area for all PHMA survey sets from 2006-2012. Number of samples are indicated in bold at bottom of the graph for each year.

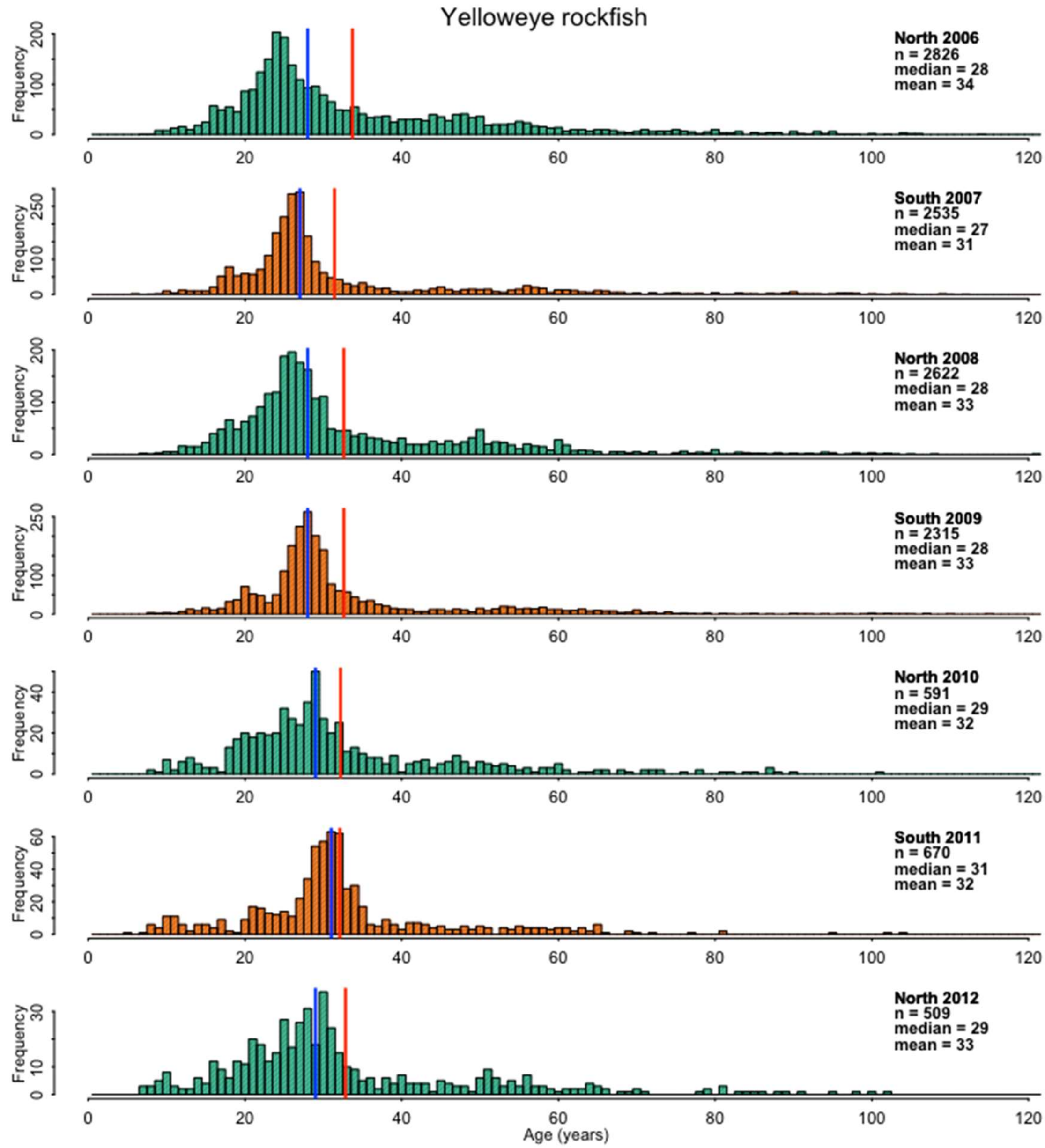

Figure A.5. Age frequencies for Yelloweye Rockfish in Northern (green bars) and Southern (orange bars) PHMA surveys from 2006-2012. Vertical lines indicate median age group (blue) and mean age (red).

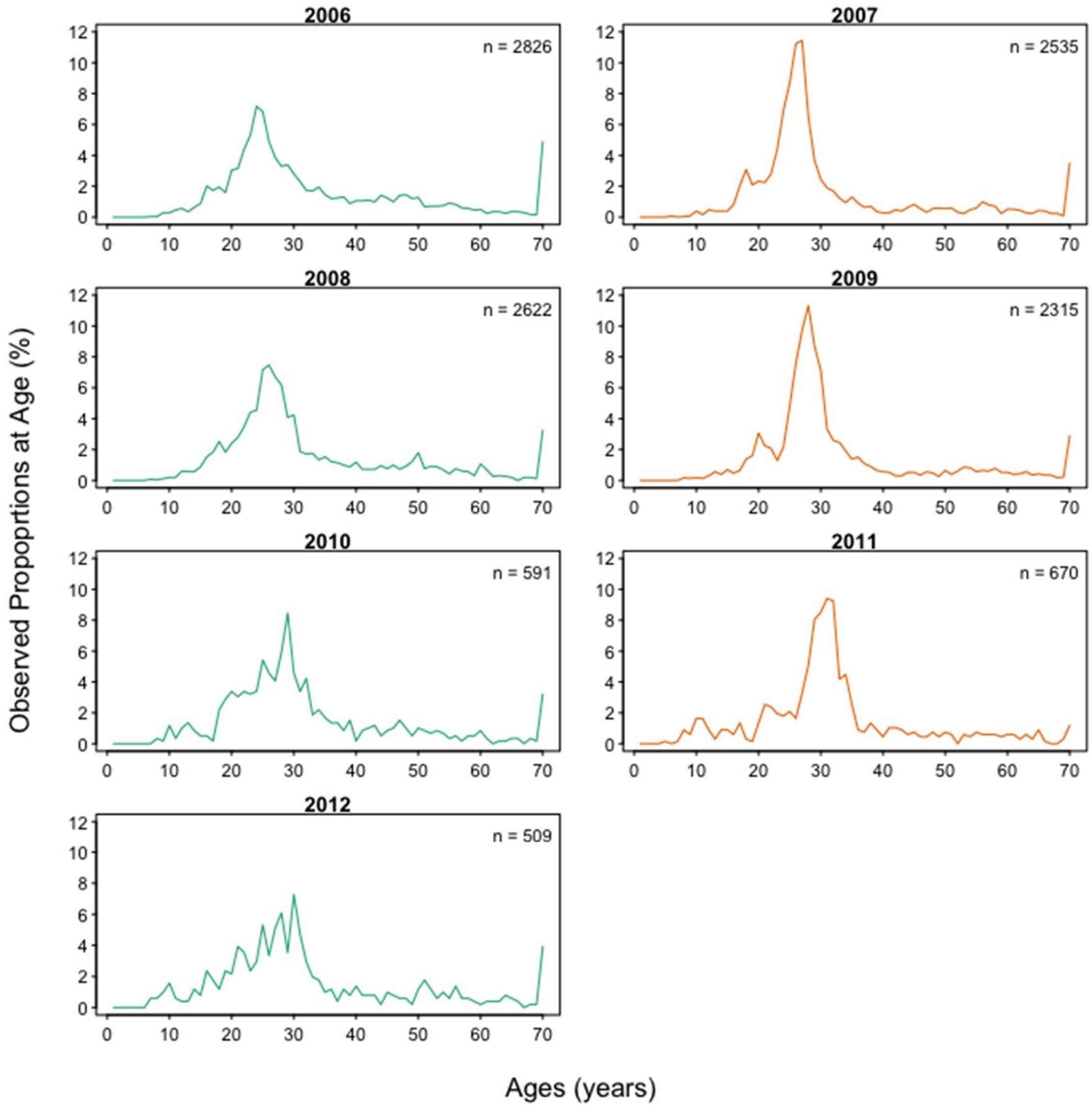

Figure A.6. Observed proportions of Yelloweye ages in Northern (left) and Southern (right) PHMA surveys for all age data from 2006-2012. Ages 70 and greater are amalgamated into a plus group.

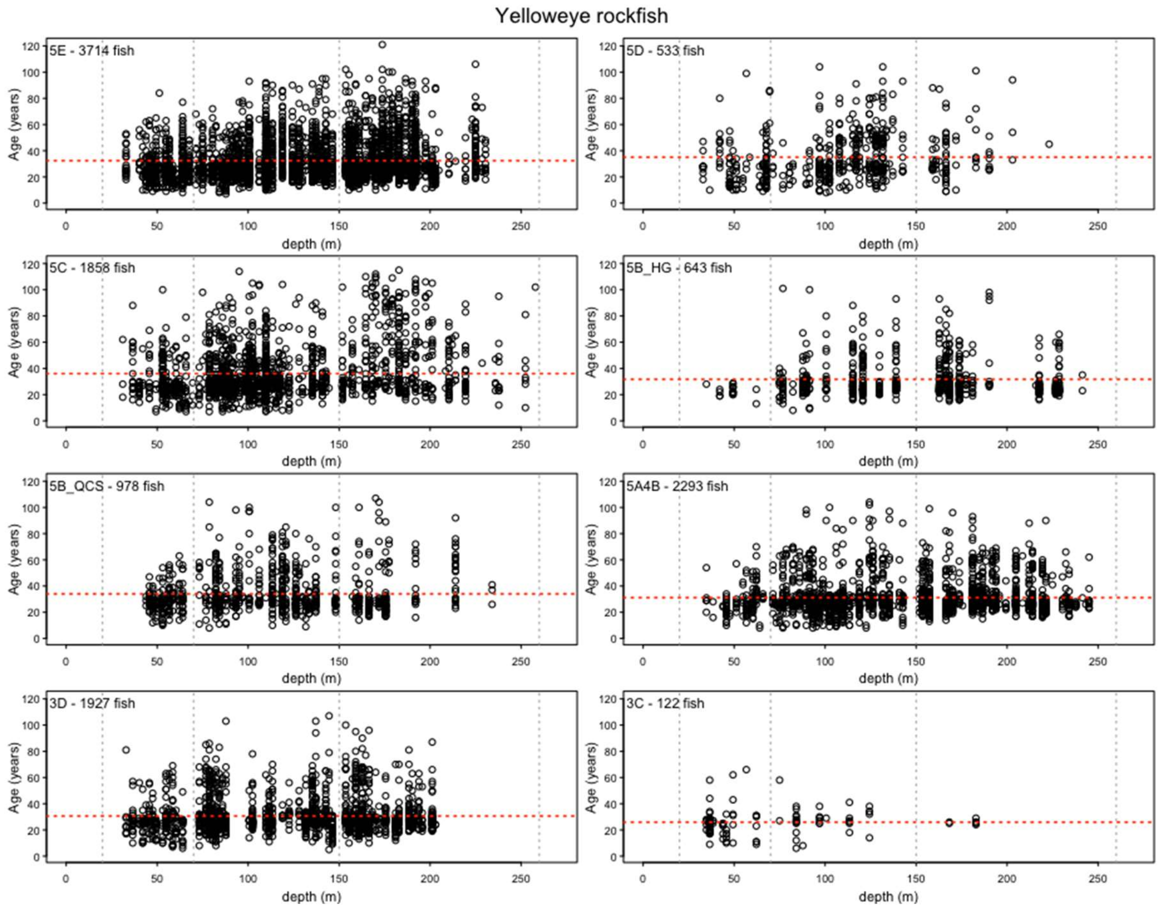

Figure A.7. All 2006-2016 age data for Yelloweye Rockfish by depth and management area. Dotted vertical lines indicate depth strata boundaries and dotted horizontal red lines indicate the mean.

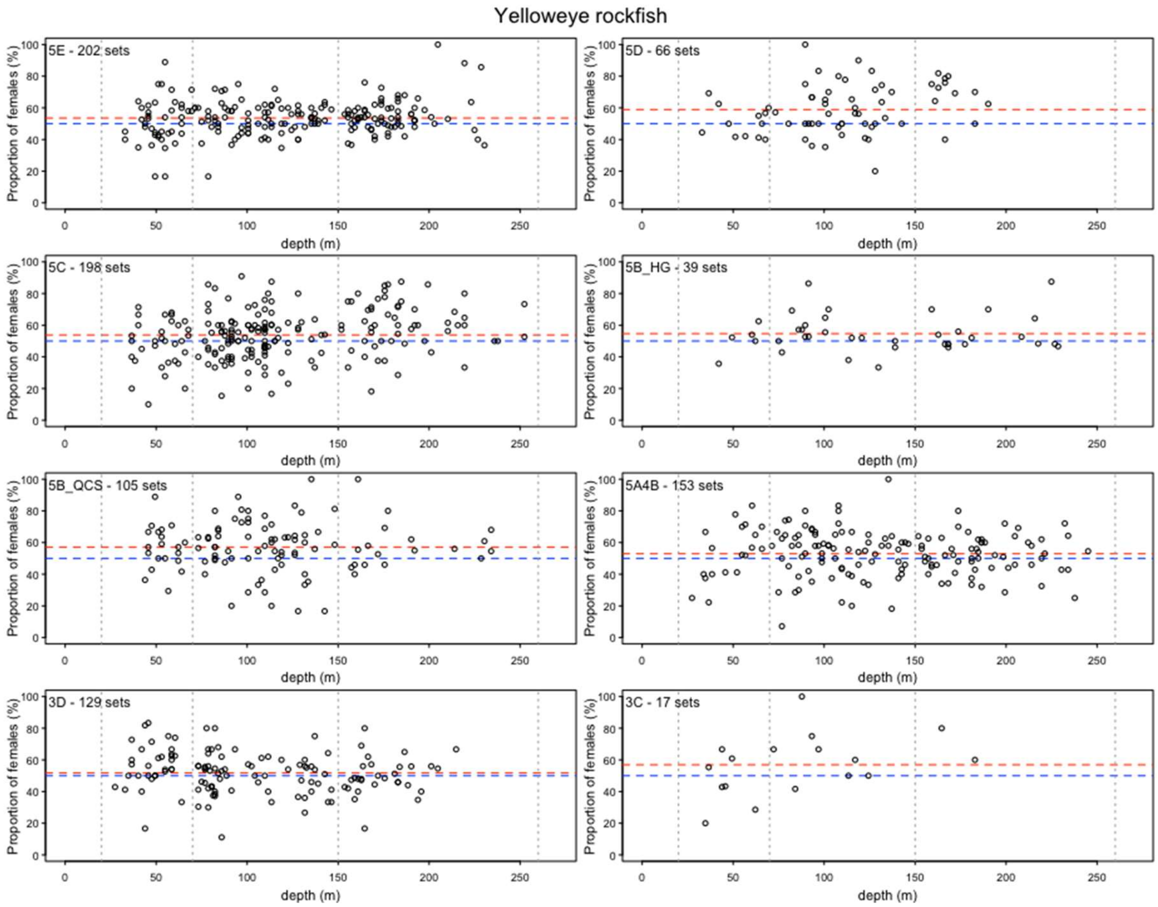

Figure A.8. Proportion of female Yelloweye Rockfish in each survey set from 2006-2016 for sets with at least 5 fish samples, shown by depth and management area. Each dot represents the proportion of females in the catch from one survey set. Dotted vertical lines indicate depth strata boundaries and dotted horizontal lines indicate the 50% proportion (blue) and mean (red).

APPENDIX B - QUILLBACK DATA SUMMARY FIGURES

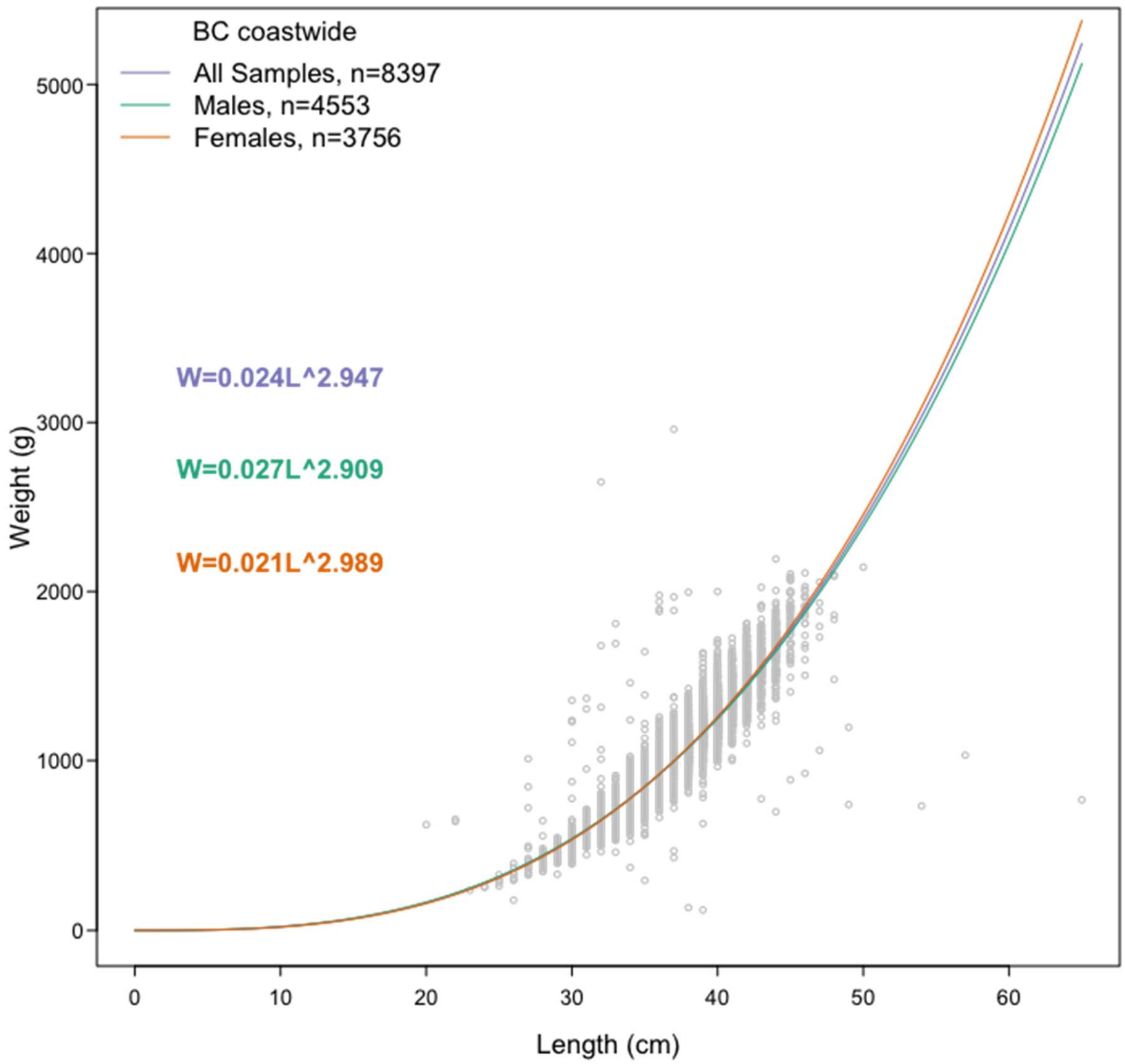

Figure B.1. Length-weight relationship for Quillback Rockfish for all PHMA survey sets with weight and fork length data from 2009-2016.

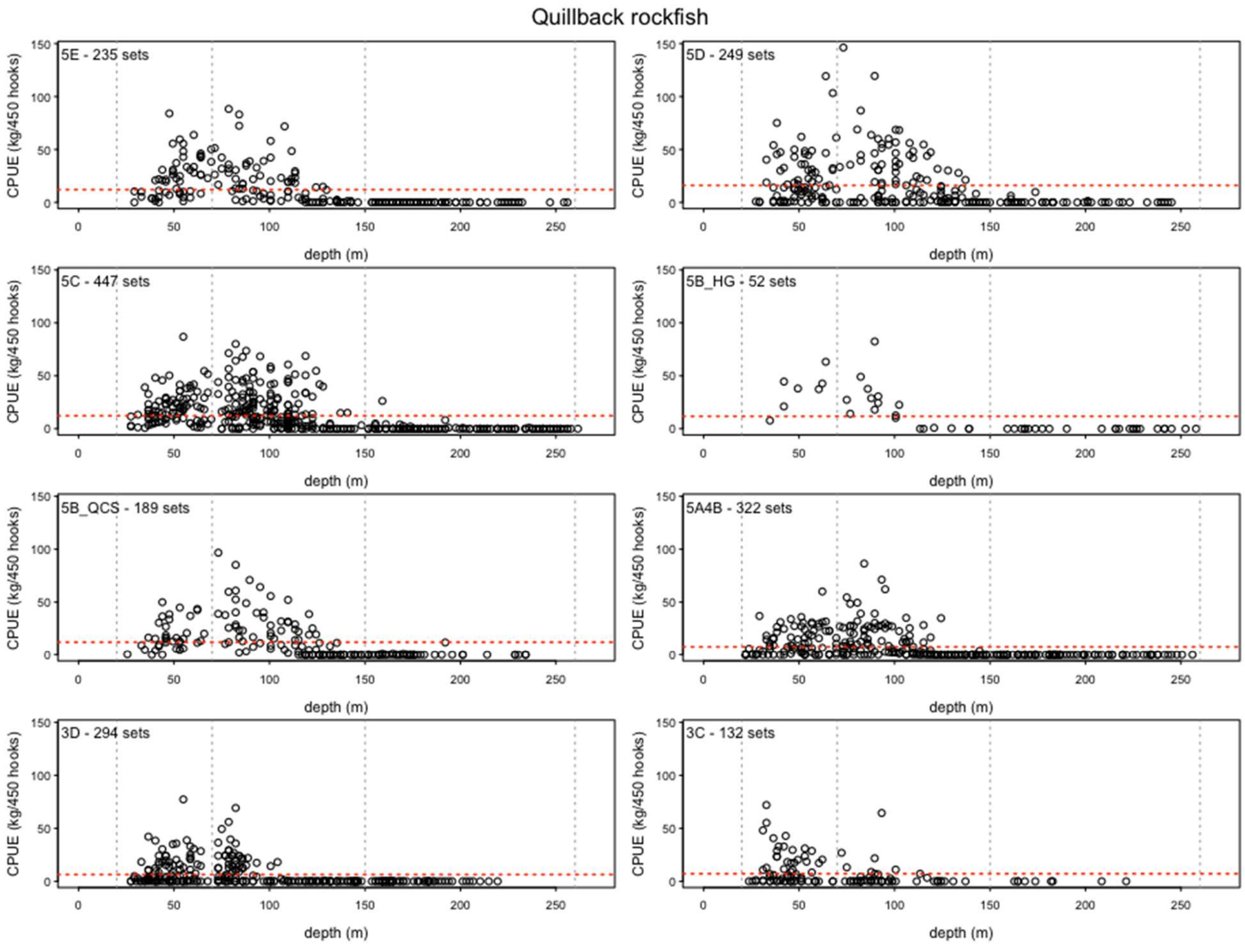

Figure B.2. CPUE (kg/450 hooks) by depth for Quillback Rockfish for PHMA survey sets from 2006-2016 for different management areas. Dotted vertical lines indicate depth strata boundaries and dotted red lines indicate the mean.

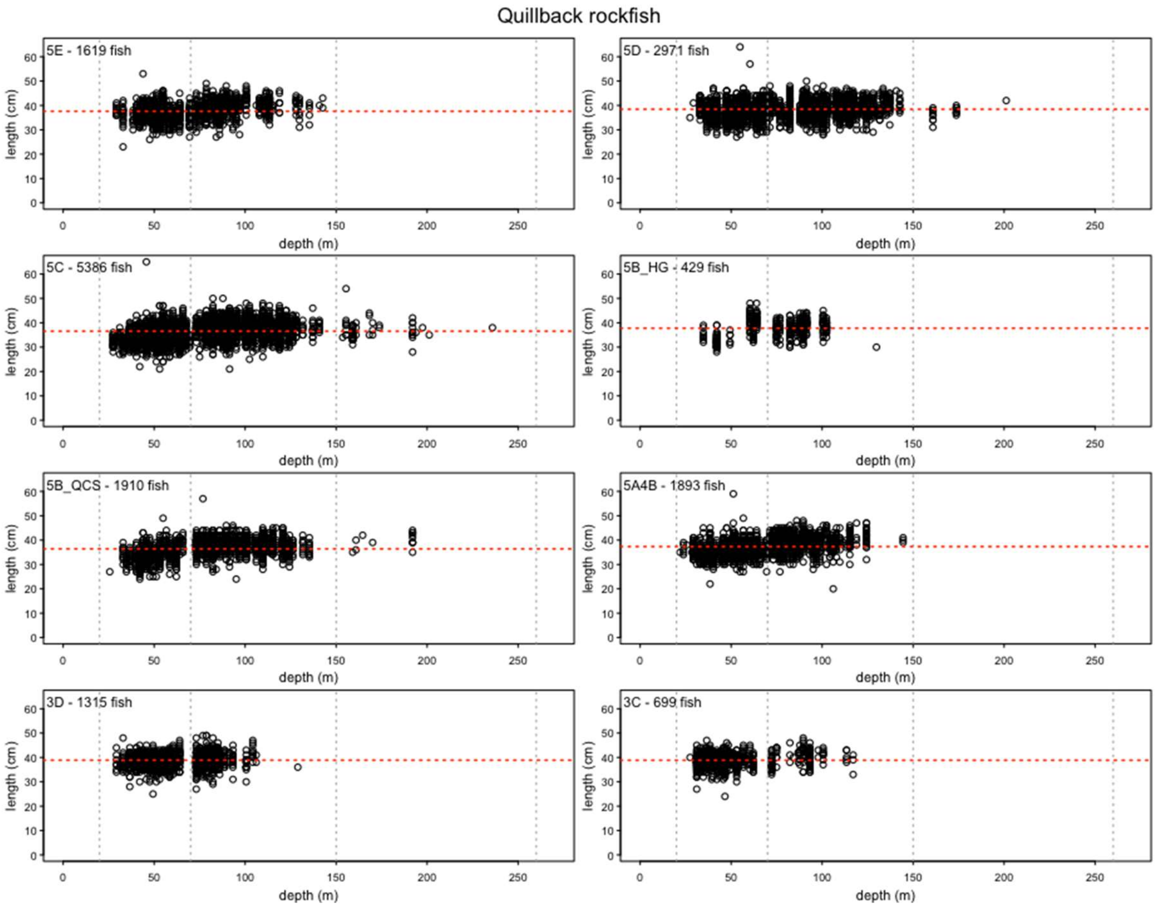

Figure B.3. All length data for Quillback Rockfish by depths for different management areas for all PHMA survey sets from 2006-2016. Dotted vertical lines indicate depth strata boundaries and dotted red lines indicate the mean.

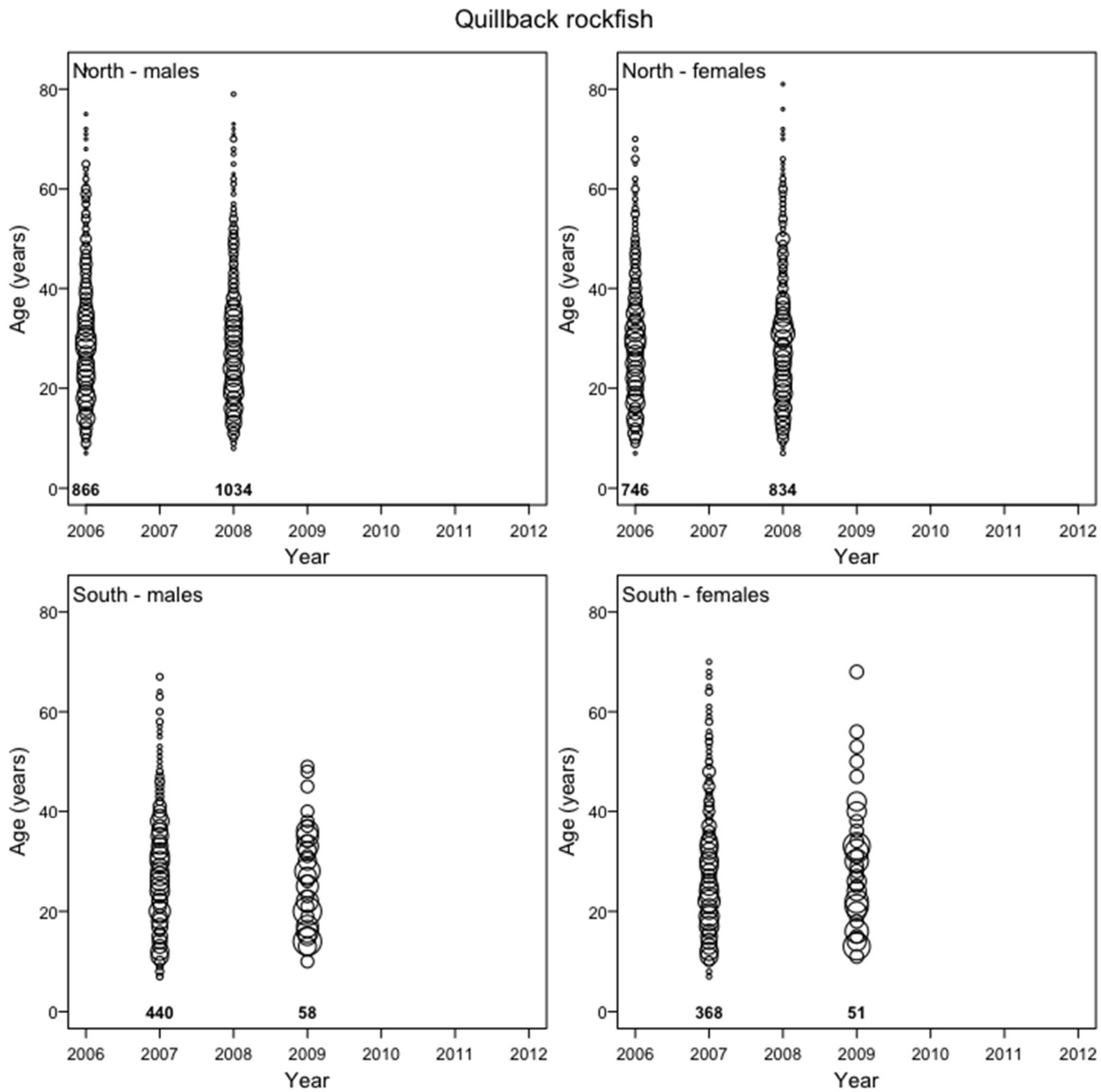

Figure B.4. Quillback Rockfish ages by sex, year, and survey area for all PHMA survey sets from 2006-2012. Number of samples are indicated in bold at bottom of the graph for each year.

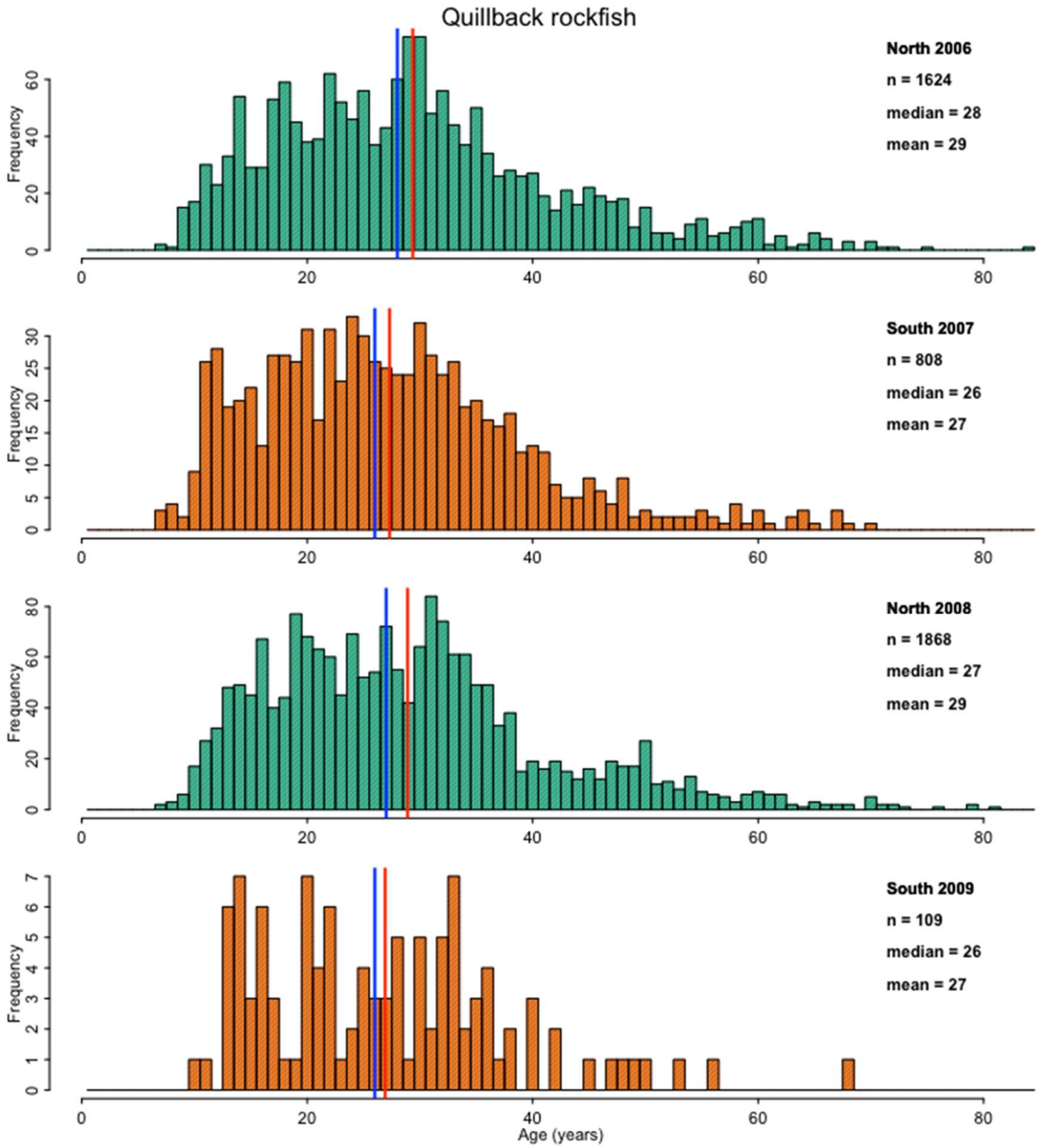

Figure B.5. Age frequencies for Quillback Rockfish catch in Northern (green bars) and Southern (orange bars) PHMA surveys from 2006-2009. Vertical lines indicate median age group (blue) and mean age (red). Note small sample size for 2009 and that no age data was available for 2010-2016.

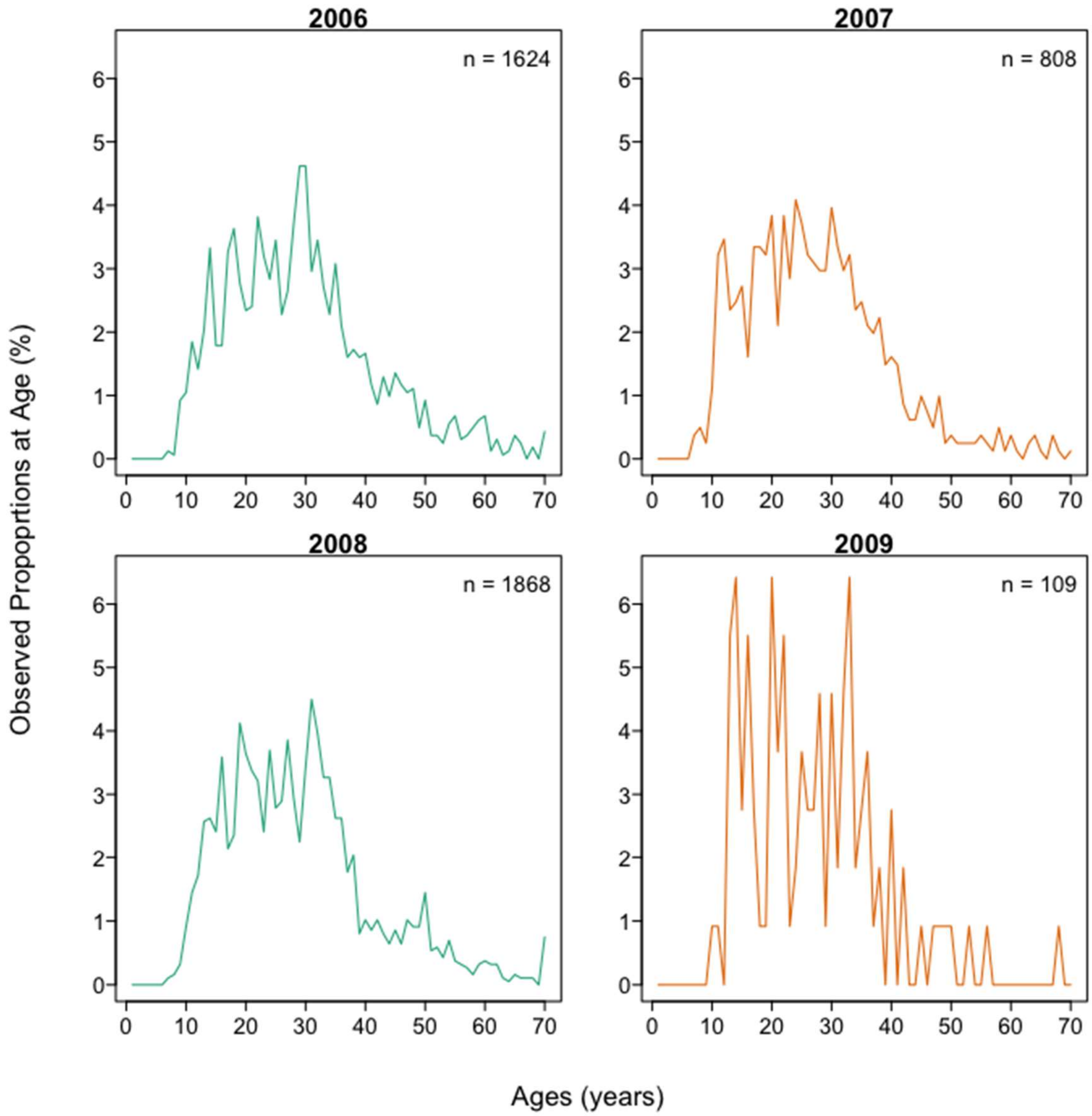

Figure B.6. Observed proportions of Quillback ages in Northern (left) and Southern (right) PHMA surveys for all age data from 2006-2009. Ages 70 and greater are amalgamated into a plus group.

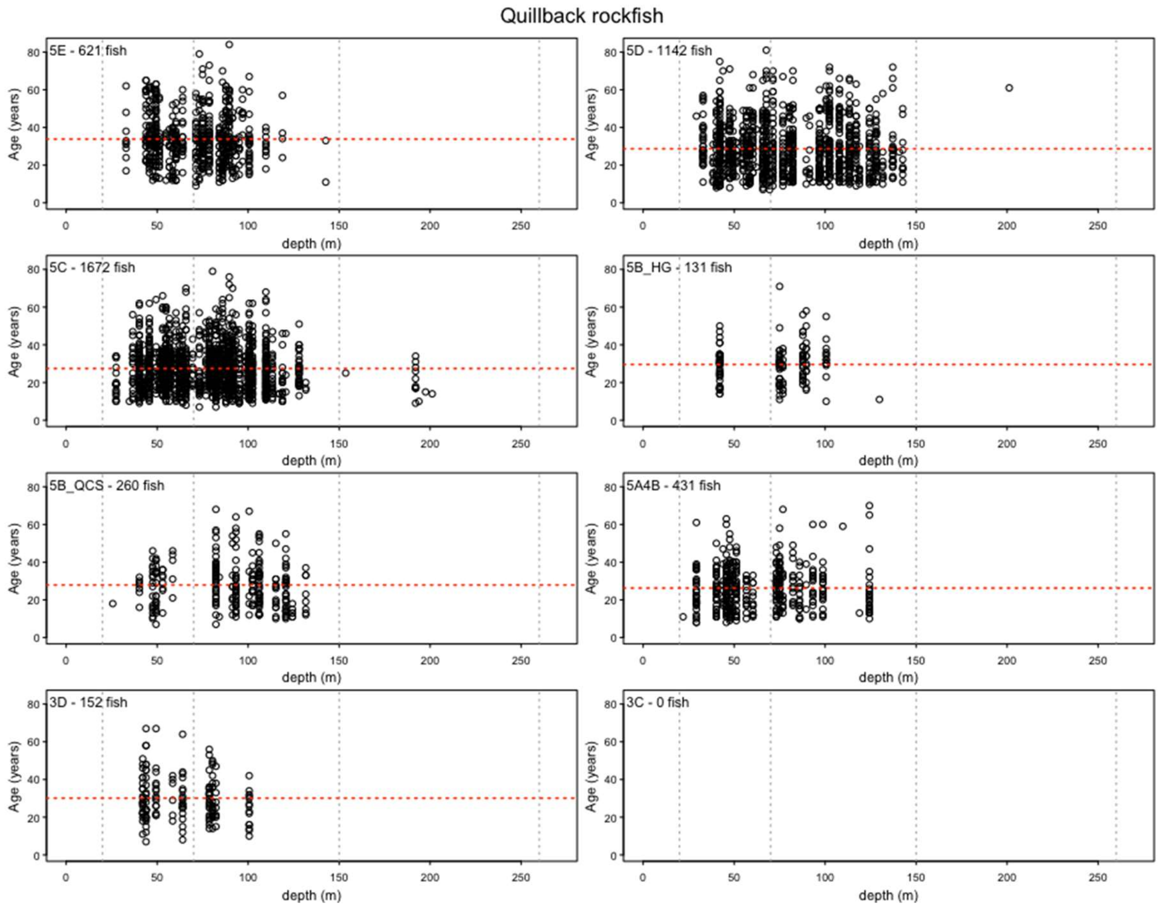

Figure B.7. All 2006-2009 age data for Quillback Rockfish by depth and management area. Dotted vertical lines indicate depth strata boundaries and dotted horizontal red lines indicate the mean. There was no age data available for 2010-2016.

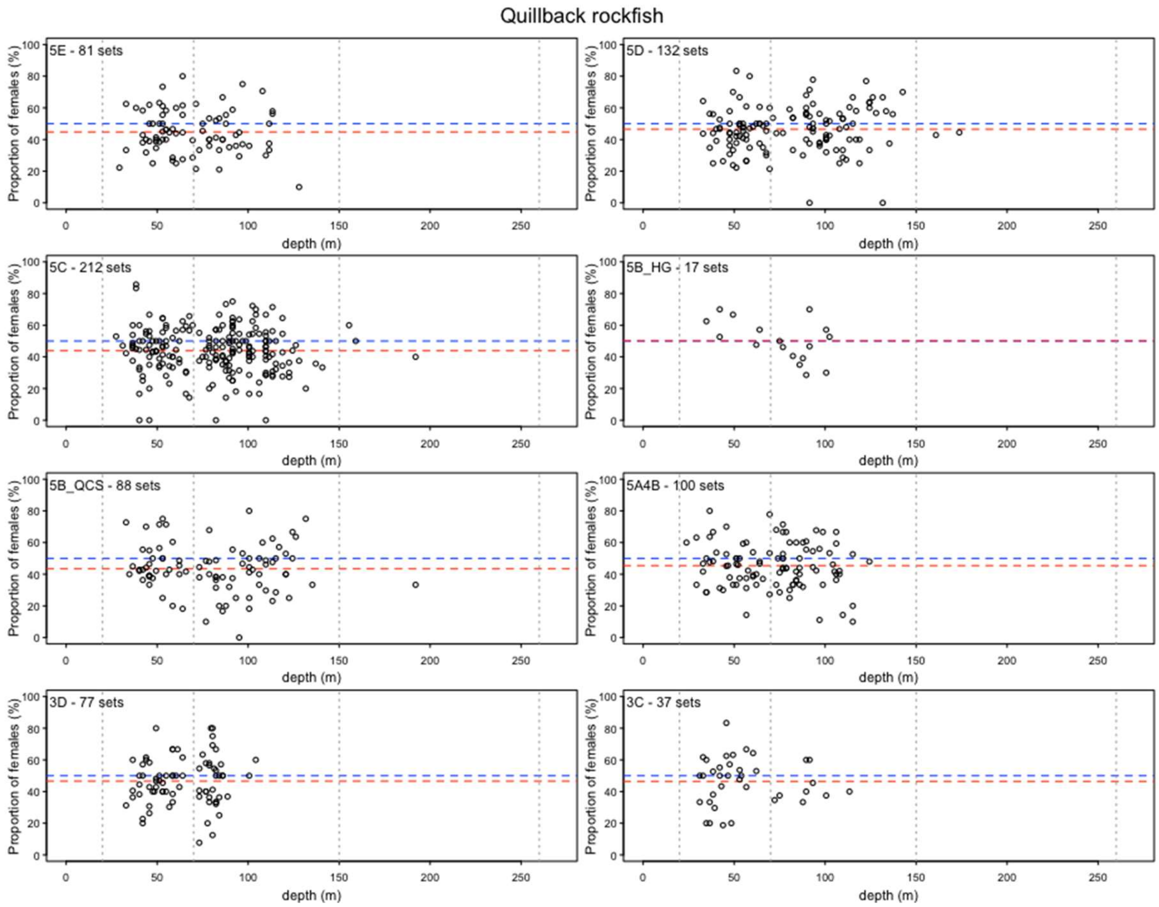

Figure B.8. Proportion of female Quillback Rockfish in each survey set from 2006-2016 for sets with at least 5 fish samples, shown by depth and management area. Each dot represents the proportion of females in the catch from one survey set. Dotted vertical lines indicate depth strata boundaries and dotted horizontal lines indicate the 50% proportion (blue) and mean (red).