

Notes on the IPHC setline survey design, alternatives for estimating biomass distribution, and the hook competition adjustment

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Abstract

This report provides a summary of issues and concerns with three important matters affecting the apportionment of biomass among regulatory areas. First, we discuss the advantages and disadvantages of the current setline survey design and potential alternative designs. Next, methods alternative to the use of setline survey WPUE for estimating the distribution of biomass among regulatory areas are examined and found to have serious disadvantages over the current survey apportionment methodology. Finally, we compare the IPHC method for adjusting the survey WPUE index for hook competition with what appeared to be an alternative method, and find them to be mathematically identical.

IPHC setline survey design

The IPHC uses a fixed station systematic survey design in which stations are spaced at 10 nm intervals. The grid starting point was effectively random, which is important for ensuring that the survey provides unbiased data. There are alternative designs that have been used elsewhere for similar large scale surveys. In particular, stations could be randomly located, with locations either fixed over time, or randomized each year; and stratification could be employed, so that the survey area is divided into contiguous strata and stations allocated to each stratum. Here we briefly compare some of the advantages and disadvantages, both statistical and logistical, of the present design with designs using randomization and stratification.

Fixed or changing station locations

The IPHC setline survey uses stations that are fixed in position, with the same stations being surveyed every year. This has a major advantage over a design in which stations move every year: variability from one year to the next is lower, and we have more precise estimates of changes in the survey index with time. Some calculations using recent survey data show that the standard error of the estimate of change in WPUE between consecutive years is around 30-40% less for our fixed station design than a design with varying locations. Such a fixed grid design may not be appropriate for a species with little movement due to possible local depletion from using the same location each year, but this is not the case with halibut, which are highly mobile, and we have no concerns that the current design is causing local depletion.

The IPHC fixed station design also has the advantage of continuously sampling a range of habitats, meaning the survey is sensitive to distributional changes of the resource, particularly those associated with expansion or contraction of the resource associated with abundance changes. A design in which the station locations change with time may be less sensitive to detecting such changes.

Regular grid or random station location, and some notes on bias

A regular grid allows for easier planning of the survey operation than a random layout with variable distances between stations. It also ensures that station density is the same throughout the survey region. Standard errors of the survey WPUE index are estimated assuming that the stations are independently sampled, which is true of a random station layout, but not true of a regular grid. Spatial dependence among the survey stations' WPUE exists: stations closer in space are generally more likely to have similar WPUE than stations far apart in space. This leads to estimated standard errors that are likely to be lower than the actual standard errors, although this is very much a minor disadvantage of the grid design. We are currently working on modeling spatial dependence among stations, which could allow us to improve our estimates of survey precision.

The estimator of mean WPUE for each regulatory area will be unbiased in both a regular grid design if the starting point of the grid was randomly chosen (systematic random sampling, as used in the current IPHC survey) and a fully randomized design.

There appears to be some confusion regarding what is meant by the term “bias”. The WPUE estimator would be unbiased if we were to set our grid an infinite number of times with different random starting points and find the average WPUE value equaled the true value. It does not mean that the WPUE value we obtain in a single year equals the true, underlying WPUE value. In fact, the estimated WPUE will never exactly equal the true value because of random variability in the samples. How much it is likely to depart from the true value depends on the sample size and the amount of variability in the data. With very large sample sizes in most regulatory areas, the estimated mean WPUE for an area is likely to be close to the true value for the sampled region. (An exception is Area 2A, and for this reason we are giving its survey design particularly close attention.) To further clarify, there very well could be halibut “hot spots” that are missed by the grid (presumably because they are small and fall between stations), but this does not mean the design is biased. Prior to placing the grid, each potential station location (from 20-275 fm, with a few exceptions such as shipping channels) had an equal probability of being selected: some “hotspots” would be hit, some missed, some areas with few halibut would be chosen, others would be missed. On average, the large sample sizes ensure that it balances out.

Bias can be a concern in any design, and we have two potential sources of bias. One is due to using a survey with stations in the range 20-275 fm to index a depth range of 0-400 fm. Unless WPUE in the unsurveyed depths has the same average as WPUE in the surveyed range, the mean WPUE we obtain from the survey will be biased. It is for this reason that we are exploring an expansion of the current survey to deeper and shallower waters (Hare et al., 2011). Second, for logistical reasons, we have excluded relatively small parts of some areas from being surveyed, for example, because of the dangers of high shipping traffic, or because strong currents make it extremely difficult to follow the survey protocol. As part of our review, we will be examining all such unsurveyed areas in detail.

Stratification

Dividing the survey area into strata, and allocating sampling stations to these strata, can be useful if it is desired to get estimates of mean WPUE for the strata, or to get more precise estimates of mean WPUE over a regulatory area when variability within strata is less than variability among strata. It is not clear what would be a useful basis for stratification of the IPHC setline survey. Depth stratification would be an obvious choice, but WPUE can vary

greatly within the same depth range, and therefore it is likely there is little, if any, benefit in terms of precision of using a depth stratification. Figure 1 compares means and approximate 95% confidence intervals of survey WPUE calculated using the usual unstratified approach and using a depth stratification of current survey stations. Use of the stratified mean provides no improvement in the precision of the index. Were we to design a stratified survey from scratch, it would doubtless be different in terms of strata definitions and allocation of stations to strata than this post-stratification, but in any case, the precision of the index is very good in most regulatory areas with the current design. In an area where precision is poorer (i.e., Area 2A), it makes more sense to consider modifications to the design in that area than a wholesale redesign of the survey.

Conclusions on using the survey to estimate the distribution of EBio

The coastwide stock assessment requires a companion process to apportion the coastwide biomass estimate into regulatory area biomass estimates. The IPHC setline survey catch rate, weighted by bottom area, provides the most objective, consistent, and statistically reliable method of estimating the distribution of Exploitable Biomass (EBio). The survey covers essentially the entire range of the population, takes place mid-year when biomass is at approximately its average level for the year, has between 50 and 300 stations per regulatory area, provides precise estimates of average density, and comprises a continuous 13-year time series of the entire coastline. Further, survey-based apportionment of biomass is the standard accepted methodology, used wherever it is available, and sees particular application in the groundfish fisheries of the north Pacific.

The IPHC staff noted, from its initial use of survey-based apportionment (Clark and Hare 2007, IPHC Staff, 2008), that the single largest concern was potential regional differences in catchability, i.e., the relationship between halibut density and survey catch rates of halibut. Staff has analyzed several factors that might affect catchability (Webster and Hare 2010). These have included: bottom area vs. station depth distribution, differences in hook availability due to competition for baits, and differences in survey timing relative to fishery removals. Statistically significant differences have been found but the adjustments to the WPUE indices are still relatively minor across almost all areas (Area 2A and parts of Area 4 show larger differences).

The staff has also analyzed alternative sources of relative abundance data to validate survey-based estimates of relative abundance. Comparisons have been made between setline survey catch rates and catch rates from scientific trawl surveys conducted by other agencies and these show no consistent pattern of differences in catchability (Clark 2008). Comparison of biomass estimates from NMFS trawl surveys and survey-based partitioning of IPHC assessment biomass are strikingly similar (Hare 2010a). In short, the body of scientific evidence to date supports the use of the IPHC survey data as a valid and defensible means of determining, for the purposes of setting catch limits, the distribution of halibut EBio.

Alternatives to estimate EBio distribution and/or catch quotas

In addition to the advantages and support of using the survey WPUE to apportion biomass discussed in the previous section, this approach is consistent with the method used to combine the individual regulatory area data components within the coastwide stock assessment. In all instances, an evaluation should focus on whether a proposed method is scientifically sound, achieves the goal of both coastwide and regulatory area management, provides protection for area-specific spawning contributions, and is sensitive to stock abundance changes.

The methodology by which biomass and/or catch limits for each IPHC regulatory area are determined has varied over time. Further, there are potentially other methods that might be considered and have been proposed by different components of the IPHC constituency. These previous and other methods are briefly summarized below, with comments on their perceived utility.

Closed-area assessments

EBio estimates were based on closed-area assessments for Areas 2B, 2C, and 3A from the late 1980s until 2007. Closed-area assessments were additionally conducted from 2002 until 2007 for Areas 3B, 4A, and 4B. Area 2A EBio was estimated as a proportion of Area 2B while 4CDE was based on the NMFS trawl survey. The closed area assessments were abandoned for several reasons. The closed area models were often difficult to fit and had convergence problems but more importantly, led to highly implausible results. Area 2C was estimated to have a biomass greater than Area 3B despite having half the bottom area and a survey WPUE less than half of Area 3B's. The closed area models estimated catchability in Area 2C to be 2-3 times as great as in Area 3B, a conclusion unsupported by any other analysis. The cause of this discrepancy was eventually diagnosed as resulting from attempting to fit closed-area assessment models to open populations. The PIT tag program had demonstrated that ontogenetic migration extended well past the age of recruitment into the EBio, thus invalidating one of the central tenets of closed-area assessment model fitting. Model testing showed that even relatively small net immigration or emigration rates had large effects on estimated EBio, resulting in sustained higher-than- expected exploitation rates in some areas and lower rates in others. The clear conclusion from the PIT-tag results was that individual closed-area assessments had been in error and could not continue to be implemented since the areas are not closed to fish movement. A coastwide assessment model was implemented, assuming the coastwide stock behaves like a closed stock. This coastwide assessment model fitted the data extremely well and provided sensible results.

Spatially-structured coastwide model

Following the 2007 CIE review (Francis 2008, Medley 2008) of the halibut assessment and harvest policy, both reviewers suggested that it might be feasible to construct an assessment model intermediate between the closed-area and the coastwide model, i.e., a spatially-structured coastwide model that would generate assessment-based estimates of EBio distribution. In theory, staff agrees that such a model is desirable and potentially feasible. There is little doubt that the area-specific abundance estimates obtained with such a model would be largely determined by the migration rates. The migration rates obtained from the PIT tag experiment cannot be reliably decomposed into the sex, size, and age-specific rates that would be necessary for accurate movement estimation in such a spatially structured model. There will always be the need to know the variability of migration rates by year, area, sex, and age and the PIT tag experiment cannot provide estimates of all these factors even for the years when it was conducted. In contrast, the assessment survey, which takes an annual snapshot of sex, age, size, and WPUE distribution, would seem far preferable as a means of tracking the relative distribution of biomass. Finally, we note that a migratory model of the type discussed was fitted to regulatory area data back in the 1980s ("migratory CAGEAN"). That model was abandoned after substantial modeling effort due to insurmountable problems, including convergence difficulties, confounding of mortality and migration, probability of variable migration rates, and negative population estimates. Building such a model anew would, given the available data, be

unlikely to overcome the problems encountered with the previous attempt at migratory modeling. It is questionable whether biomass estimates from such a model would be less controversial than those of the survey-based method. Nevertheless, staff will continue to assess the potential for development of some form of migratory model and will report upon such efforts as progress is made.

Commercial WPUE-based apportionment

In precisely the same manner in which the setline WPUE indices are used, regulatory area commercial WPUE indices could be used to apportion biomass. And, in fact, this type of apportionment was done by the IPHC early in the 1980s. The method was abandoned for reasons which still stand today. The foremost problem with commercial catch indices relates to the "hyper-stability" of the indices, and lack of proportionality to abundance. Hyper-stability of WPUE in the commercial fishery is a result of the commercial fishing process where, unlike the assessment survey, harvesters can change regions and fishing methods to maximize catch. Therefore, declines in true abundance will not be directly reflected in the commercial WPUE. This phenomenon can be seen in a comparison of IPHC setline and commercial WPUE indices. The decline in commercial WPUEs over the past decades range from 25% of 75% of the decline seen in the setline WPUEs (Hare 2010a). Basing apportionment on commercial WPUE favors areas where catch comes out of relatively few high WPUE areas. Further compounding the problem is that WPUE is weighted by habitat, currently defined as all bottom area between 0 and 400 fathoms. It would be highly inappropriate to apply a WPUE obtained from a few small areas of high density to the entire region. To properly use commercial WPUE as a basis for apportionment would require defining habitat as actual regions fished and this type of determination and computation would require annual revision and be difficult to determine precisely. These issues are not unique to the halibut fishery, and in most world fisheries, harvesters have strong incentives to avoid areas of low WPUE and move around to find areas of higher WPUE, even when facing drastic reductions in stock size. There are several cases in the history and theory of fisheries of dramatic collapses due in part to reliability on commercial WPUE (for example, northern cod).

Historical shares

Historical catch shares for the most part reflect catch limits established under the old methodology of closed-area assessments. Closed-area assessments were dependent on assumptions of migration that have been shown to have been erroneous given recent PIT tag results. Furthermore, closed-area assessments have been shown to produce erroneous estimates of biomass. Therefore, catch limits and relative catch shares, derived from that method have been shown to have been in error in some areas. Historical catch shares were also affected by factors such as higher harvest rates in previously underexploited areas, changes in the assessment model from age- to length-based selectivity, leveraging methods used in western areas to develop quotas prior to 2000, and many other extenuating circumstances. In addition, since they are fixed in time, these catch limits cannot be expected to reflect true stock biomass distribution or stock productivity. Finally, fixed catch shares allow for no feedback to changes in the distribution of abundance. This apportionment method is unresponsive to any worsening or improvement of conditions in any one area.

Blending of commercial WPUE and historical shares

Members of the halibut fishing industry proposed blending indices such as commercial WPUE and historical shares as a means of apportioning biomass. There are a number of serious issues with the blending of methods, as discussed and illustrated with simulation modeling during recent IPHC sponsored workshops (Valero and Hare 2010a, 2010b). First, is the underlying merit of the individual components proposed in the blending, as discussed in previous sections. Historical catch shares reflect catch limits established under the old, erroneous, methodology of closed area assessments. Commercial WPUE is likely to be hyperstable, meaning that it tends to be less responsive to changes in stock size.

Second, is the issue of weighting of the indices: if we were to weight according to the reliability of each index, then both historic shares and commercial WPUE should receive relatively much lower weights given the reasons summarized above. The third issue is the objective for the blending: the objective advanced by advocates was to provide stability and predictability in the quota system setting process. However, most natural systems are highly variable and Pacific halibut is no exception. Sustainable management of natural resources relies on timely and appropriate responses to those changes. An extreme case of stability and predictability in quota setting (at least in the short term or if using extremely low harvest rates) would be to have fixed quotas for each area of the halibut stock. However, this method is completely unresponsive to changes in abundance and, at any desirable harvest rates, would not lead to sustainability. Even if we picked an appropriate fixed share method, it would still be unable to respond to abundance changes. An apportionment method based on a standardized survey (not only supported by IPHC staff but also broadly used regionally, nationally, and internationally) should track stock changes both coastwide and on an area basis.

Annual Surplus Production

Annual surplus production (ASP), i.e., the amount of catch that can be taken such that biomass remains constant over time, has been widely used in other fisheries as the basis for setting quotas. Further, there have been recent calls for a return to the use of ASP, at least as part of the process of diagnosing stock trends (Hilborn 2001, Walters et al. 2008). The IPHC routinely published and relied upon estimates of ASP to set coastwide catch levels during the 1980s as part of an explicit stock rebuilding strategy. Subsequently, an ASP-based apportionment methodology was developed, though ultimately unused, to set regulatory area catch quotas. The IPHC has recently revived the practice of computing and publishing regulatory area ASP estimates (Hare 2010b). There are, however a number of considerations and difficulties in basing catch quotas on ASP. To determine regulatory area ASP, estimates of EBio within each area are required. As such, it is in a sense a derivative of the method used to apportion biomass. This in itself is not a problem, however, ASP is often highly volatile and can be a negative value in times of stock decline (i.e., there is no surplus production, biomass would decline even in the absence of catch). Further, ASP-based quotas provide no information on the conservation level of the biomass, it simply seeks to maintain biomass at the present level. Thus, an area with low biomass, if the full ASP were taken as quota, would not be capable of building to a higher, potentially more productive, level.

IPHC hook competition adjustment

IPHC staff has developed several adjustment factors to the survey CPUE indices to correct for possible regional differences in catchability. One of the potential differences is competition

for hooks resulting from different suites and densities of competitors. IPHC staff has developed a method (Clark 2008, Webster and Hare 2010) which adjusts CPUE on the basis of available baits, reasoning that areas where baits disappear more rapidly have an effectively lower fishing effort relative to areas where more baits remain available.

What appeared to be a mathematically different, but conceptually similar, approach to adjusting a longline survey CPUE index for the effects of hook competition was developed for the Canadian Department of Fisheries and Ocean's rockfish survey (Etienne et al. 2010). Here we show the IPHC method and the Etienne et al. (2010) approach to have the same mathematical formulation.

The IPHC method (Clark, 2008) uses the Baranov catch equation to model the number of baits, B_i , removed by a predator after a time period, T :

$$B_i = B_0 e^{-\frac{F_i}{Z} (1 - e^{-ZT})}$$

where F_i is the instantaneous rate of bait removal by predator i , B_0 is the initial number of baited hooks, and $Z = \sum_j F_j$ is the sum of the instantaneous rates applied by all bait takers. It follows that the expected catch of halibut, which is one of the bait predators, is given by

$$C_h = B_0 e^{-\frac{F_h}{Z} (1 - e^{-ZT})} \quad (1)$$

For the survey, soak time is assumed to be of sufficient length that catches of all species are unaffected by the exact value of T . For simplicity, we therefore set $T=1$ in the above equations. It is further assumed that empty hooks are due to bait taking by species other than halibut, and, therefore, halibut do not escape once captured. In these equations, $(1 - e^{-Z})$ is the fraction of baits removed by all takers during the active period. An estimate of Z is therefore given by $\log(B_0/B_1)$, where B_1 is the number of baits remaining when the gear is hauled.

In a given year, the hook adjustment factor (HAF) for area j is calculated by dividing the coastwide value of average baits remaining, $(1 - e^{-Z_{CW}})$, by the value of average baits for area j ,

$$HAF_j = \frac{1 - e^{-Z_{CW}}}{1 - e^{-Z_j}}$$

with the estimates of Z_j and Z_{CW} plugged in. This is multiplied by the WPUE for that area to give the adjusted WPUE.

Etienne et al. (2010) propose using a multinomial exponential model (MEM) to describe the bait removal process. For our purposes, we again assume that empty hooks are due to species other than halibut, although Etienne et al. (2010) do consider more general models. The MEM model assumes that the time it takes a bait to be removed by the target species (i.e., halibut in our case) follows an exponential distribution with removal rate λ_h , and that the time it takes for bait

to be removed by other species also follows an exponential distribution, with parameter λ_o . With soak time again denoted by T , and letting $I=0$ be the event that the hook is still baited at the end of time T , it follows that the probability a hook has its bait removed prior to hauling is given by

$$P(I=0) = e^{-\lambda T}$$

where $\lambda = \lambda_h + \lambda_o$. The probability the bait was taken by a halibut is

$$P(\text{Halibut}) = \frac{\lambda_h}{\lambda} (1 - e^{-\lambda T}),$$

and the expected catch of halibut is therefore

$$C_h = B_0 \frac{\lambda_h}{\lambda} (1 - e^{-\lambda T}),$$

where B_0 is again the initial number of baited hooks. It is clear that there is an equivalence between this expression and Equation (1), i.e., $\lambda = Z$ and $\lambda_h = F$. Indeed, the maximum likelihood estimator of λ is given by $\log(B_0 / B_1)$, the estimator used by the IPHC for Z . This perhaps should not be surprising, since the Baranov catch equation, which is the basis for the IPHC hook adjustment, is derived from the assumption that mortality follows an exponential process, and so both the IPHC's method and that of Etienne et al. (2010) have the same mathematical derivation.

Where the authors differ slightly from the IPHC is that they propose using the halibut (target species) rate of capture, λ_h , as an index of density, whereas we multiply the WPUE index by the adjustment factor given above. The maximum likelihood estimate of λ_h is given by

$$\hat{\lambda}_h = \frac{N B_h}{B_{01} B_{10} B_{11} B_{12}} \log \left(\frac{B_0}{B_1} \right) \frac{1}{CPUE}$$

and therefore λ_h can also be expressed as an adjusted CPUE index. However, it is straightforward to show that for a single year's data, apportionment based on $\hat{\lambda}_h$ is identical to apportionment using the adjustment factors HAF_j given above. The index $\hat{\lambda}_h$ differs from an adjusted IPHC CPUE index in that the latter does not allow for a coastwide adjustment for hook competition, even if the coastwide average amount of hook competition changes over time: the coastwide adjustment factor is always 1, i.e., no adjustment. The index of Etienne et al. (2010), therefore, may provide a better measure of changes in survey density with time than the IPHC adjustment approach. Modifying the IPHC method to allow for temporal changes in coastwide

hook competition is straightforward when dealing with a CPUE index: we simply remove the coastwide standardization in HAF_j above, giving:

$$HAF_j = \frac{1 - e^{-Z_j}}{Z_j} \frac{Z_j}{1 - e^{-Z_j}} \left(\frac{BB}{BBB} \right) -$$

Multiplying this by CPUE gives us $\hat{\lambda}_h$. For our purposes, we could replace CPUE with WPUE to get an adjusted index based on weight, although it would no longer be in lbs/skate, and some may find such an adjusted index more difficult to interpret. Alternatively, since $1 - e^{-\hat{\lambda}_h}$ is an estimate of the fraction of baits that catch halibut in the absence of competition, we can multiply this by the standard number of hooks per skate and the mean weight of a legal-sized halibut captured in that survey region to get an adjusted WPUE value in terms of lbs/skate.

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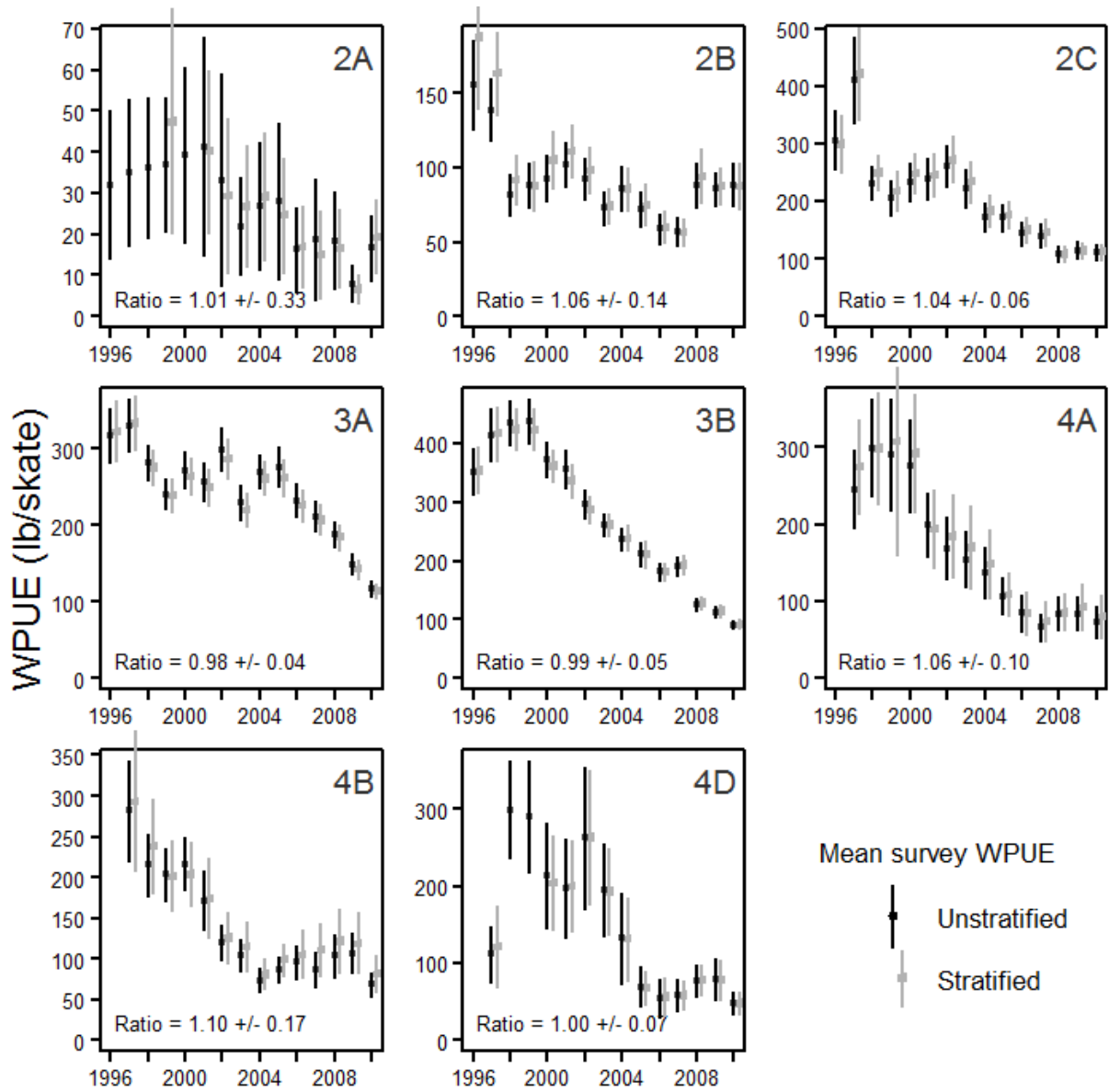


Figure 1 Comparison of unstratified and depth stratified mean WPUE estimates, with approximate 95% confidence intervals ($\pm 2SE$).