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Independent Validation of the Accuracy of Yelloweye Rockfish Catch Estimates from the Canadian Groundfish Integration Pilot Project

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Abstract.—The British Columbia fishing industry and the Department of Fisheries and Oceans Canada introduced 100% monitoring of the commercial groundfish hook-and-line and trap fisheries in April 2006. The monitoring system includes cameras to capture video footage of hauling at the vessel's side, Global Positioning System-linked winch sensors on all boats, 100% dockside monitoring of piece counts and weights, and 100% retention of all rockfishes *Sebastes* spp. The system provides official estimates of total catch in pieces and weight (retained and discarded) through the fisher logs and dockside monitoring. Using catches of yelloweye rockfish *S. ruberrimus* as a test case, this study examined the accuracy of catch estimates produced during the third year of the program (April 2008 to March 2009). The analysis indicates that the overall monitoring produces accurate catch estimates of yelloweye rockfish. A key, and possibly unique, component of the catch verification was the derivation of an alternate estimate of total catch. This estimate was derived from the data that result from the video review of randomly selected fishing events. This review process randomly selects 10% of the events from each trip and enumerates the catch of each species during the entire event. Originally designed as a random check on the veracity of the fisher logs, these review data were used in this study to provide an unbiased estimate of mean catch per event and its variance; mean catch per event was then expanded to total catch by the total number of events. Since these data come from video footage collected at the moment of capture, the video estimate cannot be corrupted by misreporting of discards or by dumping fish after being retained. Thus, the video data provide an unbiased and virtually independent catch estimate—rare in fisheries monitoring—that captures the extent to which the official catch accounting systems might be biased.

The Canadian Groundfish Integrated Pilot Project (CGIPP) was initiated in early 2006 by the commercial groundfish industry and the Department of Fisheries and Oceans Canada (DFO). The intent of the 3-year project was to rationalize the various groundfish license categories that use hook-and-line (HL) or trap gear to harvest groundfish in British Columbia waters (for an introduction to the project, visit www.diamondmc.com/Content/Home.asp?langid=1). One of the key elements of the project was the development of a monitoring system that could provide accurate estimates of the catch of each species, particularly the specimens that are discarded (disposed at the moment of capture) or dumped (disposed subsequent to capture; Koolman et al. 2007; Yamanaka and Logan 2009). The second key element of the project was the introduction of individual vessel quotas (IVQs) wherein each vessel is assigned a proportion of the overall quota of select species and can catch, lease, or sell these privileges.

The project has been in place for just over 3 years and thus has been given sufficient opportunity to overcome the problems of implementation. It is therefore reasonable now to critically evaluate the effectiveness of the monitoring. Results of a first test case of the project's catch monitoring, as applied to yelloweye rockfish *Sebastes ruberrimus*, are presented. The yelloweye rockfish was selected for this analysis because of concerns over the conservation status and the lack of accurate discard data for this species in particular and for rockfishes *Sebastes* spp. in general—concerns that gave much of the impetus to the CGIPP (Yamanaka and Logan 2009). This analysis uses results from the third and most recent fishing year (FY) extending from April 1, 2008, to March 31, 2009 (FY 2008–2009).

The overall focus of this article is whether the monitoring system is providing sufficiently accurate

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TABLE 1.—Total catch of yelloweye rockfish (pieces) by groundfish license sector as recorded in fisher logs and the Dockside Monitoring Program (DMP) for fishing year 2008–2009 in outside and inside regions along the coast of British Columbia. Weight of catch for all sectors combined is also shown.

Sector	Total catch in pieces		Total catch in weight (kg)
	Fisher logs	DMP	
Pacific halibut (outside)	39,880	39,988	
Pacific halibut/sablefish (outside)	10,411	10,128	
Lingcod (outside)	2,008	2,056	
Rockfish (inside)	554	519	
Rockfish (outside)	14,159	14,063	
Sablefish (outside)	292	304	
Spiny dogfish (inside)	1,581	1,563	
Spiny dogfish (outside)	3,499	3,531	
Total (outside)	70,249	70,070	215,588
Total (inside)	2,135	2,082	4,289
Total (coastwide)	72,384	72,152	219,877

estimates of total catch to allow managers to be confident that harvests are not exceeding quotas for the quota species. This "conservation risk" is distinguished from the "operational risk" of poor catch data, wherein the latter refers to whether the monitoring tracks the catches of individual fishers with sufficient accuracy to ensure a level playing field among fishers in an IVQ context.

For the IVQs to have trading value, fishers must share the perception that other fishers cannot cheat the system. For example, harvesters of Pacific halibut *Hippoglossus stenolepis* must possess sufficient quota of yelloweye rockfish to cover the incidental capture of yelloweye rockfish while Pacific halibut are targeted. The trading of the IVQ for yelloweye rockfish or any other quota species would break down if it were perceived that fishers could secretly discard or dump quota species. Fishers recognized early in the planning stages of the project that an IVQ system could not function without sufficiently accurate catch monitoring to minimize the operational risk noted above.

Description of the Project Monitoring System

The CGIPP catch monitoring covers HL and trap fishing conducted by vessels with commercial groundfish licenses in British Columbia waters. Excluded from this analysis are groundfish catches in the commercial trawl and salmon troll fisheries, as well as catches in the recreational and the First Nations' fisheries. Oversimplifying somewhat, groundfish vessels using HL or trap gear conduct their fishing trips within one of five groundfish license or sector categories. These categories are distinguished in this article as the rockfish, Pacific halibut, sablefish *Anoplopoma fimbria*, lingcod *Ophiodon elongatus*, and spiny dogfish *Squalus acanthias* sectors. Sablefish and Pacific halibut fishers sometimes conduct trips under a combination category, the Pacific halibut–sablefish sector (Table 1).

Some of the sectors can only fish in one or the other of two management regions for yelloweye rockfish but not in both (Figure 1). The exceptions are the lingcod and spiny dogfish fishers, who may fish in both regions during the same trip, but this is rare in practice. For this analysis, these trips were classified as being in one region or the other based on where the majority of the events took place within the trip. The rockfish outside and inside regions are distinct sectors (Yelloweye rockfish are treated in this article as inside and outside populations following Yamanaka et al. 2006. The current management plan further divides the outside quota into four subregions [www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/plans09/2009GroundfishAug21.pdf].)

For FY 2008–2009, the separate overall commercial groundfish quotas for yelloweye rockfish were 270 metric tons for the outside region and 7 metric tons for the inside region. These were divided among the sectors and then further subdivided among the vessels as their IVQs. While IVQ privileges can be sold or leased to other vessels, there are restrictions on how much can be accumulated per vessel and sector.

The project monitoring is composed of three key programs: (1) the fisher logbooks; (2) the Dockside Monitoring Program (DMP); and (3) the Electronic Monitoring Program (EMP). The fisher logs provide the fishers' piece count records of catch by species for each fishing event. Catch is defined as the catch of all specimens (retained or discarded) that rise above water level at the vessel's side during fishing, including those that are shaken loose by fishers during retrieval.

The EMP provides video footage (VF) of the retention or discarding of all fish at the hauling site during all fishing events (McElderry et al. 2003; Ames et al. 2007). The cameras are recording at all times as the gear is being hauled. The EMP also includes a Global Positioning System-linked vessel monitoring system (VMS) connected to the winches; the VMS tracks vessel location during fishing to confirm the fishing location of each event in the fisher logs. Fishers may choose to take an observer in place of the EMP; this option was used for 17 of the 1,274 trips during FY 2008–2009, mostly in the Pacific halibut–sablefish sector.

The role of the DMP is to provide validation of the piece counts of select species and total weights of all species during unloading for all trips. The piece counts and weights are obtained under the review of

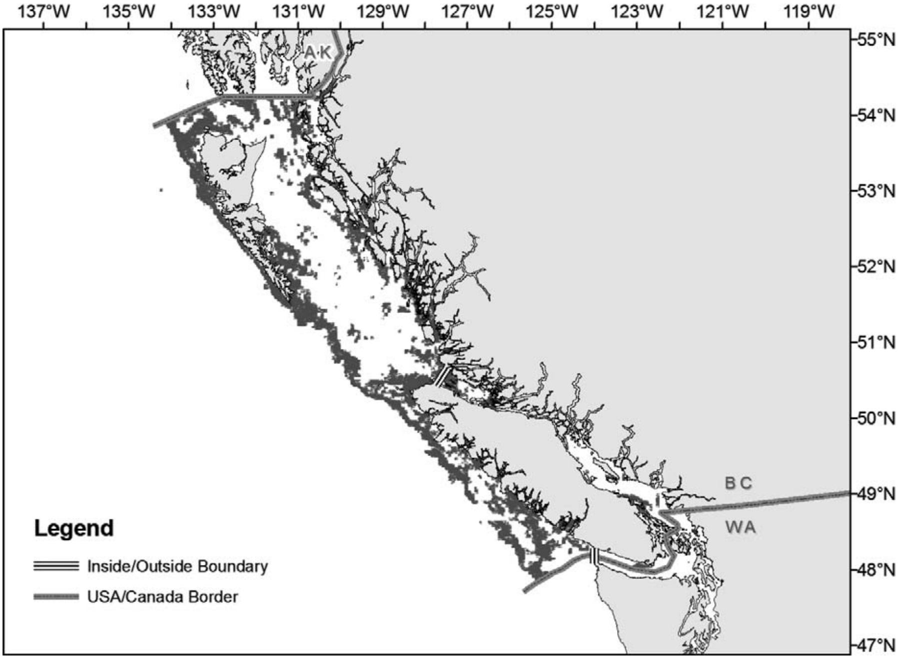

FIGURE 1.—Chart of the coast of British Columbia, showing the outside and inside management regions for yelloweye rockfish and fishing locations from April 2006 to March 2008. Note that for confidentiality purposes, only locations (5- × 5-km blocks) where at least three vessels have fished are shown.

independent contractors. This is done even for live specimens. Owing to (1) the difficulty in distinguishing among some rockfish species during video review and (2) the potential for discard mortality, managers mandated that all rockfish must be retained during fishing and unloaded during dockside monitoring ("100% retention"). The DMP landed weights are used to track the official quota status of yelloweye rockfish and all other quota species for each vessel.

A key, and possibly unique, element of the monitoring is a random audit of the fisher logs. Within 2 weeks of the unloading of each trip, the VF from 10% of the events of each trip is reviewed to enumerate catch in pieces (retained and discarded) by species for the entire event. The 10% target translates in practice to be one event for trips with 1–14 events, two events for trips with 15–24 events, three events for 25–34 events, and so forth. The VF piece counts are then compared with the fisher log for the same events. If the counts match within a prescribed tolerance for select quota species, the fisher logs for that trip are deemed valid and the fisher logs become an official record of total pieces caught (retained and discarded) by species for all events in the trip. If the deviations exceed the prescribed tolerances, the VF for all events of the trip may have to be reviewed at vessel expense ("100% VF review") to provide an alternative record of total catch in pieces for that trip. The vessel may also have to take an observer on the next trip, also at vessel expense. Although prohibited, if the fisher logs contain records of discarded specimens, such as yelloweye rockfish, these can be converted to weight (by using a mean weight per piece in the fishery), added to the landed weights that are assigned to the vessel's cumulative catch, and counted against the vessel's IVQ. However, this has not proved necessary.

The intent of the VF audit of fisher logs is to validate the logs and, in particular, confirm the veracity of fishers' records of discards and retained pieces. In the case of rockfish, VF audits are intended to provide confirmation that no rockfish were discarded and that the DMP landed weight and piece count provide a true record of total catch. While a 100% review of the VF would be preferable, the costs of complete review were deemed unacceptable in that the fishery would have become uneconomical for many of the participants.

Although the VF audit of fisher logs confirms information on discarding, unreported dumping (disposal of fish after being recorded in the fisher logs but prior to unloading) remains a possibility. For the different rockfish species, this can be checked by comparing the total piece counts noted as retained in the fisher logs with the DMP piece count for that trip. If the DMP piece count is significantly lower than the fisher log retained piece count, then it can be assumed that the fisher surreptitiously disposed of yelloweye rockfish before the DMP check at unloading by using the specimens for bait, unloading them illegally, or simply dumping them. For example, when targeting Pacific halibut, fishers may not have sufficient yelloweye rockfish IVQ (in weight) attached to their vessels to cover the incidental capture of yelloweye rockfish that could accrue during targeted Pacific halibut fishing. Rather than purchasing additional IVQ of yelloweye rockfish, these fishers may attempt to misrepresent the yelloweye rockfish catch. Even though the fisher log could be correct, there is no way to detect the dumped fish through a comparison between the fisher log *piece* count and the DMP *weight* since the mean weight of yelloweye rockfish varies widely among trips. Therefore, a piece count is obtained during the DMP in addition to the total weight, albeit at significant cost and inconvenience to the fisher, especially in the live rockfish fishery.

As with the comparison of fisher logs and VF, if deviations in the fisher log data from the DMP data do not fall within prescribed tolerances, the trip may be subjected to 100% review and the vessel may have to take an observer on future trips at the vessel's expense. If the deviations are large, the fisher log piece counts can be converted to total weight and used in place of DMP weight for IVQ tracking of vessel catches.

If no yelloweye rockfish have been discarded or dumped, the fisher logs and DMP provide two different estimates of the total yelloweye rockfish catch in pieces for each trip, and the DMP also provides total catch in weight. Since all trips are monitored, summing the catches over all trips provides two estimates of total catch in pieces (fisher log or DMP piece estimate) and one of total weight (DMP weight estimate). In addition, the fisher logs, verified by the VMS, indicate where, when, and how the fishing was conducted, which allows the catches to be allocated to the appropriate region. Since the fisher logs record piece counts and location for each event (confirmed by the VMS), the DMP piece counts and DMP landed weights can be prorated to area by using the piece counts in the fisher logs. In addition to providing confirmation on the location of the catches, VMS is used to ensure that there is no fishing in closed areas or during closed periods.

In summary, the fishery is operationally managed within the year under the default assumption that the DMP is a correct record of retained catches by weight. The fisher logs confirm that there are no discards of quota specimens and are used to assign catch to region. However, a series of audit checks is applied to the fishing logs and DMP of each trip to verify that the operational assumptions are valid. If they are shown to have been violated for individual trips, alternative data sources (i.e., 100% VF review) are available to provide a corrected catch record for these trips.

The system has been operational since April 2006 and appears to be successful. For the first time, not only are there credible bycatch estimates available for yelloweye rockfish and other quota species for all sectors by region (Table 1), but these fish are all now retained for sale, whereas much of this catch would previously have been discarded.

The monitoring also appears to have the confidence of the majority of the fishers. While there have been complaints, mostly about the cost, there is no suggestion that the fishers think the IVQ system is failing owing to significant misreporting. After an adjustment period in the first year, most fishers now receive passing scores in the fisher log and DMP validation steps. It is also reassuring that the total fisher log and DMP piece counts for yelloweye rockfish match overall (Table 1), as do the total counts from the fisher logs and VF for the subset of reviewed events representing about 10% of the fishery (Table 2). Finally, the conservation risk is minimized given that the total catch is less than the quotas (Table 2).

While the monitoring system gives the appearance of working, it has been noted from early in the design phase of the project that in spite of the quality assurance checks, it might still be possible to cheat the system. For example, fishers might under-report the piece count by 5% in their fisher logs, knowing that this level of bias will fall within the tolerances of the VF audit of fisher logs. The same fisher may then dump an additional 5% of the yelloweye rockfish pieces prior to unloading, knowing that this 5% mismatch would lie within the tolerances of the DMP audit of fisher logs. If all fishers were to push these tolerances, then actual catch could exceed reported catch by 10% or more. This concern left managers wondering whether to assume there would be an overage of the quota simply because it would be possible.

Such concerns are common in most, if not all, catch monitoring programs. Even 100% observer programs are often questioned for their precision and particularly their bias (Kelleher 2005; Lennert-Cody and Berk 2007). In most cases, the monitoring is designed and conducted as well as is reasonable, and it is assumed to be adequate. Nevertheless, while rarely attainable, it will always be preferable to have some independent means for estimating the bias and precision of the official catch estimates. The key intent of this article is

TABLE 2.—Comparison of the total piece count of yelloweye rockfish between fisher logs and video footage (VF) reviewed events in outside and inside regions along the coast of British Columbia during fishing year 2008–2009.

Region	Reviewed events	Total piece count	
		Fisher logs	VF data
Outside	2,721	7,813	7,857
Inside	247	286	244
Coastwide	2,968	8,099	8,101

to demonstrate a somewhat fortuitous outcome of the video monitoring. The observations collected during the VF review (VF data), although collected for the random fisher log audits, provide a virtually independent and unbiased estimate of total catch in pieces.

Methods

Catch estimation from the VF data is simple in concept. Since the reviewed events are, in theory, chosen at random, one can simply expand the mean catch rate in the reviewed sets by the total number of sets in the fishery. Although the review process examined 12% of all events and the target rate of 10% of events per trip was achieved for 91% of the 1,274 trips (Table 3), 6% of all trips received no review (Table 4). In addition, in a few of the reviewed trips some individual events were nonreviewable. In these cases, an alternative event from the trip was randomly selected to review in its place to meet the 10% target for that trip. A more detailed discussion of the reasons and implications for not meeting the target is discussed below (see Discussion). The distribution of trips by number of events reviewed per trip is summarized in Table 4. Most trips are represented by five or fewer reviewed events.

Not all trips were represented in the VF data; therefore, the estimates were derived after stratifying the samples. Each sector defines a nonoverlapping stratum of all possible fishing events for each year, as follows. For a given year, let H denote the number of strata and let N_h represent the number of events in stratum h. The total number of events is then given by the sum $N = N_1 + N_2 + \cdots + N_H$. Suppose that a simple random sample of n_h events is selected for review from the N_h possible events in stratum h. Observations y_{hi} are the piece counts of yelloweye rockfish from each event $i = 1, \ldots, n_h$. Following the usual probability sampling formulas (Scheaffer et al. 1979), the estimator of the mean count per event for stratum h is defined by

$$\bar{y}_h = \sum_{i=1}^{n_h} y_{hi}/n_h. \quad (1)$$

The estimated variance of the stratum mean is given by

$$V(\bar{y}_h) = \frac{s_h^2}{n_h}\left(\frac{N_h - n_h}{N_h}\right), \quad \text{where}$$

$$s_h^2 = \frac{1}{n_h - 1}\sum_{i=1}^{n_h}(y_{hi} - \bar{y}_h)^2. \quad (2)$$

For any combination of strata, the estimator of the stratified mean is the weighted sum of the individual stratum mean estimators, namely

$$\bar{y}_{st} = \frac{1}{N}\sum_{h=1}^{H} N_h \bar{y}_h. \quad (3)$$

Similarly, the estimated variance is given by

$$V(\bar{y}_{st}) = \frac{1}{N^2}\sum_{h=1}^{H} N_h^2 \left(\frac{N_h - n_h}{N_h}\right)\left(\frac{s_h^2}{n_h}\right). \quad (4)$$

The corresponding estimator of the stratum total is

$$\hat{\tau}_h = N_h \bar{y}_h, \quad (5)$$

with estimated variance

$$V(\hat{\tau}_h) = N_h^2 \left(\frac{N_h - n_h}{N_h}\right)\left(\frac{s_h^2}{n_h}\right). \quad (6)$$

TABLE 3.—Number of fishing trips and video footage (VF) reviewed events for each groundfish license sector operating along the coast of British Columbia, fishing year 2008–2009.

Sector and region	Total number of trips	Total number of events	Mean number of events/trip	Total number of VF reviewed events	Overall percent of events reviewed	Percent of trips that met 10% VF review target
Pacific halibut (outside)	502	8,706	17	884	10	92
Pacific halibut/sablefish (outside)	85	2,504	29	254	10	89
Lingcod (outside)	171	2,669	16	272	10	94
Rockfish (inside)	78	1,155	15	149	13	95
Rockfish (outside)	208	3,420	16	509	15	92
Sablefish (outside)	59	3,875	66	625	16	90
Spiny dogfish (inside and outside)	171	2,587	15	275	11	82
All sectors	1,274	24,916	20	2,968	12	91

TABLE 4.—Number of fishing trips within video footage review frequency categories (reviewed events/trip) for each groundfish license sector along the coast of British Columbia, fishing year 2008–2009.

Sector	Number of events reviewed per trip						
	0	1	2	3–5	6–10	11	Total
Pacific halibut	28	183	215	73	1	2	502
Pacific halibut and sablefish	7	14	33	19	10	2	85
Lingcod	4	83	73	10	1	0	171
Rockfish (inside)	4	43	13	14	4	0	78
Rockfish (outside)	15	77	43	46	25	2	208
Sablefish	5	4	7	14	9	20	59
Spiny dogfish	17	76	59	12	7	0	171
All sectors	80	480	443	188	57	26	1,274

Similarly, the estimator of the stratified total is

$$\hat{\tau}_{st} = N\bar{y}_{st} = \sum_{h=1}^{H} N_h \bar{y}_h, \qquad (7)$$

with estimated variance

$$V(\hat{\tau}_{st}) = N_2 V(\bar{y}_{st}) = \sum_{h=1}^{H} N_h^2 \left(\frac{N_h - n_h}{N_h}\right)\left(\frac{s_h^2}{n_h}\right). \qquad (8)$$

Two weaknesses of the classical sampling estimators defined above for determining confidence intervals are (1) the lower bound of the confidence interval can be negative and (2) the interval is symmetric about the point estimate. The first weakness is a problem for count data that must be bounded below by zero. The latter weakness may result in the construction of inappropriately wide confidence intervals when the data distribution is skewed. One means of resolving these deficiencies is to use a resampling procedure, specifically the bootstrap, to provide nonparametric confidence intervals for the estimation variable (Efron and Tibshirani 1993). We describe below the application of the so-called “naïve” bootstrap algorithm, although both Rao and Wu (1988) and Sitter (1992) have proposed more elaborate bootstrap solutions for the case of stratified random sampling that provide confidence intervals with improved performance.

Here, we provide the naïve bootstrap algorithm for the stratified mean, but the steps can be applied to any statistic of interest. Within each stratum, a bootstrap sample can be obtained by randomly sampling the observed data B times, with replacement:

(a) For each stratum $h = 1, \ldots, H$, a simple random sample. $\{y_{hi}^*\}$ is independently selected with replacement from the observed sample $\{y_{hi}\}$, $i = 1, \ldots, n_h$. The usual estimator of the stratified mean (equation 3) is then computed for each resample, $\bar{y}_{st}^*$.

(b) Step (a) is independently repeated a large number of times (B), and the corresponding estimates of the stratified mean, $\bar{y}_{st}^{*1}, \bar{y}_{st}^{*2}, \ldots, \bar{y}_{st}^{*B}$, are computed.

Confidence intervals can be constructed from the distribution of bootstrap values obtained by resampling using the percentile method (Efron and Tibshirani 1993).

Following the notation of Efron and Tibshirani (1993), let G^{-1} be the cumulative distribution function of the bootstrap values $\bar{y}_{st}^{*1}, \bar{y}_{st}^{*2}, \ldots, \bar{y}_{st}^{*B}$. The $1 - 2\alpha$ percentile interval is defined by the α and $(1 - \alpha)$ percentiles of G^{-1}. For the case of the stratified mean, the bootstrap estimates $\{\bar{y}_{st}^{*b}\}$ ($b = 1, 2, \ldots, B$) are sorted, the $B\alpha$th value is chosen as the lower confidence limit, and the $B(1 - \alpha)$th value is chosen as the upper confidence limit. For these yelloweye rockfish estimates, B is 1,000 and α is 0.025. Thus, the 25th (2.5%) and 975th (97.5%) value of the ordered bootstrap estimates $\bar{y}_{st}^{*b}$ were used to form the bounds of the 95% confidence interval by sector, as well as for region and coastwide stratified means.

Results

Mean estimates and confidence limits of the piece counts for each sector and region are provided in Table 5. While the 95% confidence limits for the bootstrap estimates are about ±30%, the mean estimates closely match the official estimates provided as the sum of the fisher logs or DMP at the region and coastwide levels and even provide reasonable matches for the individual sector estimates (Table 6). The match of the piece counts indicates that the total weights reported in the DMP (Table 1) accurately reflect the actual total catch of yelloweye rockfish in the regions for these sectors.

The VF estimates of yelloweye rockfish were 13% lower than the fisher log and DMP totals for the Pacific halibut sector and 19% lower in the case of the spiny dogfish inside sector. These discrepancies require further examination; however, in the short term, since

TABLE 5.—Mean and 95% confidence limits (CLs) of the estimated number (pieces) of yelloweye rockfish captured by each groundfish license sector along the coast of British Columbia during fishing year 2008–2009.

	Pieces per event				Total piece counts		
Sector and region	Mean	Lower CL	Upper CL	Number of events	Mean	Lower CL	Upper CL
Pacific halibut (outside)	4.0	3.2	4.8	8,706	34,547	27,704	42,043
Pacific halibut/sablefish (outside)	4.5	2.9	6.2	2,504	11,144	7,153	15,596
Lingcod (outside)	0.9	0.7	1.1	2,669	2,310	1,810	2,858
Rockfish (inside)	0.5	0.3	0.7	1,155	536	335	772
Rockfish (outside)	5.0	3.5	6.7	3,420	16,991	12,120	22,894
Sablefish (outside)	0.1	0.0	0.3	3,875	359	31	1,109
Spiny dogfish (inside)	1.8	1.3	2.4	721	1,282	908	1,695
Spiny dogfish (outside)	2.4	1.3	4.0	1,866	4,496	2,380	7,430
Outside total	3.0	2.2	4.0	23,040	69,847	51,198	91,930
Inside total	1.0	0.7	1.3	1,876	1,819	1,243	2,467
Coastwide	2.9	2.1	3.8	24,916	71,666	52,440	94,398

the official estimates are higher, the possible bias does not represent a conservation risk. For cases where the VF estimate is higher than the official estimates, the discrepancies are more modest. All of the official estimates fall well within the 95% confidence limits of the VF estimates.

These discrepancies and the variance in the VF estimates could probably be reduced by further analysis of the data—particularly stratification within the sectors. Although all the fishing events within the sectors are treated as homogeneous in this analysis, they can be further stratified by such factors as season, depth, location, and gear. For example, the sablefish sector could be further subdivided into trap or longline vessels since the bycatch of yelloweye rockfish is known to be much higher when using the latter gear.

Discussion

The monitoring system of the CGIPP is now fully operational. The system validates catches in a timely manner, and the tracking of IVQs has the confidence of the fishers. Some catches that previously had to be discarded are now retained for sale (at Can$4.50/kg), and whether fish are discarded, dumped, or landed, the system appears to provide sufficiently accurate estimates of total catch to allow managers to match harvests to quota management.

A unique feature of the program is that the official total catch estimates from the fisher logs and DMP can be validated by an estimate generated from VF data. This was an unanticipated benefit of the EMP since the intent of the camera system and random review of VF was to provide an audit check on the quality of individual fisher logbooks. Because the VF is obtained before fishers can falsify the fisher logs and discard specimens, if the VF data can be treated as a random set of observations then they can provide an opportunity to obtain an unbiased estimate of the true catch along with estimates of uncertainty. Although the VF estimates are in piece counts, the DMP provides reliable estimates of mean weight per piece (by sector or region) that can be used to convert these VF piece counts to total catch in weight.

The agreement between VF estimates and the fisher log and DMP estimates indicates that unreported discarding and dumping are negligible. In fact, fishers on the project design team predicted that there would be little evidence of this bias in the results. They stated that it was already difficult enough to record their catches with enough accuracy to pass the audit tolerances. They would be unlikely to bias their logbooks or the DMP by even a few fish for fear of increasing the likelihood of failing the audits and thereby incurring the cost of 100% review, an observer, or both.

The VF estimate also provides the advantage of remaining unbiased even if some elements of the monitoring system are changed or reduced. The

TABLE 6.—Comparison of yelloweye rockfish piece counts from video footage (VF) review, fisher logs, and the Dockside Monitoring Program (DMP) for each groundfish license sector along the coast of British Columbia, fishing year 2008–2009.

	Total piece count source		
Sector and region	VF	Fisher logs	DMP
Pacific halibut (outside)	34,547	39,880	39,988
Pacific halibut/sablefish (outside)	11,144	10,411	10,128
Lingcod (outside)	2,310	2,008	2,056
Rockfish (inside)	536	554	519
Rockfish (outside)	16,991	14,159	14,063
Sablefish (outside)	359	292	304
Spiny dogfish (inside)	1,282	1,581	1,563
Spiny dogfish (outside)	4,496	3,499	3,531
Outside total	69,847	70,249	70,070
Inside total	1,819	2,135	2,082
Coastwide	71,666	72,384	72,152

project's achievements in catch monitoring in a small-boat fishery have come at considerable cost, about Can$2.6 million per year. The fishing industry and DFO, which share the cost at about 75% and 25%, respectively, are looking to reduce these costs. They have asked, for example, how the accuracy would be affected if the VF audit rate could be reduced from 10% to 5%. In particular, they suggest that the subset of fishers or vessels with a proven history of validated logbooks should have earned the right to less review and less cost.

If the audit rate is lowered, fishers will recognize that they will be less likely to be caught if they under-report discards in a given trip. Should some fishers take advantage of this change, it would cause total catch in the fisher logs to underestimate true catch. While the reduction in reporting quality will be apparent in the audit failure rate, managers would not know how biased the fisher log catch totals were becoming. Fortunately, although the VF estimates will become less certain as sample size declines, they should continue to provide an unbiased estimate of total catch. Therefore, fishery managers and industry can jointly experiment with such changes, knowing that they will not be incurring a conservation risk.

This first use of the VF data indicates the potential of VF to provide an independent estimate of total catch; however, the analytical methodology will benefit from more development. The system selects 10% of the events within each trip (with a minimum of one event), and thus the sampling design within trips is self-weighting (Lohr 1999). However, it can be argued that the results of a single reviewed event for a trip of 14 events should exert more leverage than the results of a single reviewed event for a trip of 5 events. Future procedures could consider weighting by the number of events within a trip.

Another weakness in the present method is that overall estimates of mean catch per event treat all observations as independent even though catch rates within trips are presumably correlated. This could be addressed by treating the design as two-stage sampling wherein catches are estimated for individual trips and then summed for each sector. This would certainly be the preferred method if there were consistently many VF observations per trip. It may not help in this case, where about one-third of the trips are represented by only one event (Table 4). This process would also still have to accommodate those trips that were not reviewed. More sophisticated techniques for coping with the missing data from nonreviewed trips might also improve the estimation procedure (Lohr 1999). As noted earlier, the uncertainty in the estimates might be reduced through alterative stratifications that take advantage of systematic variation in bycatch rates owing to such influences as season and gear.

A further issue, with respect to estimating catch from the VF data, lies in the capability of the reviewers to distinguish yelloweye rockfish from other species. Of the over 8,000 specimens identified as yelloweye rockfish in the 2008–2009 VF data, 369 were noted as also possibly being canary rockfish *Sebastes pinniger*. If reviewers are not confident in the identification, they can identify one or more additional species as being equally likely.

A rigorous estimation procedure would include the possibility that all of the ambiguous identifications could have been canary rockfish, and therefore the catch of yelloweye rockfish could be about 5% less. However, the close match between the fisher log counts and VF counts in the reviewed events (Table 2) indicates qualitatively that most of the 369 fish were yelloweye rockfish.

Since all of the rockfishes are retained for dockside monitoring, a better method for partitioning the ambiguous identification would be to use the observed ratio of yelloweye rockfish to canary rockfish piece counts in those landings. The dockside sorting, at least for all rockfishes, provides the basis for a more rigorous method for coping with this additional source of uncertainty, but this was not attempted for this study.

The catch estimation from VF data will be more problematic for the catches of flatfishes, large skates (Rajidae), and birds. There are specific pairings or aggregates of species in these groups that are difficult to distinguish in the VF; however, because they are not currently subject to 100% retention, the DMP sorting does not provide a backup for partitioning these catches. A full review of the project monitoring requires that the present work be expanded to address the catch accuracy for the remaining species, both quota and nonquota, in this fishery. It should be noted, however, that while it may not be possible to provide VF estimates of the individual species within these aggregates, it will be possible to estimate the total piece count of the group, such as all "birds." Although this is less than ideal, prior to the project there was no means to estimate the magnitude of the catch, so it is a major improvement to obtain a defensible estimate of the total piece count of the group. If greater accuracy by species is required for these groups, then it may be possible to derive estimates of the species ratios within these groups from observations made during fishery-independent surveys or from strategic placement of observers. It also remains an option for managers to expand the 100% retention regulation to additional species groups.

The most problematic analytical issue with respect to the VF estimates and the monitoring overall lies in the assumption that viewers can select events at random from all trips. As noted earlier, the review target of 10% of events per trip was not met for 9% of all trips, and 6% of all trips received no review. Some of these failures could be traced to mechanical problems; others, especially in earlier years, were caused because the fishers neglected to turn the system on. For those trips in which reviewers had to select alternate "random" events, the reviewers' comments indicated that some events were nonreviewable because of "poor lighting" or "water/slime" on the camera lens.

The integrity of the overall monitoring system (i.e., not only the VF estimates) will be suspect if fishers are able, or even perceived to be able, to render entire trips or selected events nonreviewable. While a small amount of equipment malfunction can be expected, the project will have to be diligent in managing this problem. With respect to complete system failures, the project has worked hard to make the EMP system more robust and satisfactory to the fishers, with the result that the proportion of trips for which the review process did not meet the 10% target has fallen steadily from 15% to 12% and now to 9% over the first 3 years of the project. However, subsequent analysis should routinely isolate the set of trips that could not be reviewed and should examine for suspicious patterns, such as repeat offenders.

With respect to those trips in which only some events were nonreviewable, the reviewers did not notice any suspicious patterns, but initially no attempt was made to electronically capture the details of why some events could not be reviewed. Thus, it was not possible in this study to examine this issue more systematically. However, as a result of this study, reviewers are now codifying these details and including these metadata in the catch monitoring database to be available for future work.

Conclusions

This review of the CGIPP catch monitoring of commercial groundfish vessels in British Columbia indicates that it is providing accurate total catch estimates of yelloweye rockfish. The relative veracity of the data was assumed by managers and fishers from the outset owing to the complex and costly verification checks built into the system. However, the unforeseen capability of the VF data to provide a virtually independent and unbiased estimate of total catch is proving to be a powerful and useful final validity check on the official estimates of total catch.

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