Discussion Paper

Halibut Discard Mortality in Recreational Fisheries in IPHC Areas 2C and 3A

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INTRODUCTION

Pacific halibut *Hippoglossus stenolepis* is a primary species harvested in marine recreational fisheries in Southeast and Southcentral Alaska. Halibut are typically caught by anglers targeting halibut, lingcod, rockfish, other bottomfish, or salmon. With a daily bag limit of only two fish, anglers often catch more halibut than they keep (harvest), especially when targeting other species. Anglers release halibut that are smaller or larger than their preferred size at that time, and release halibut that are caught after the bag limit has been reached. Catch-and-release fishing is not only allowed, it is now sometimes required in Southeast Alaska where a maximum size limit regulation implemented in 2007 stipulates that if the first halibut harvested by an angler is at least 32 inches long, all subsequent halibut caught that are over 32 inches long must be released. In the absence of size limits, many anglers on charter boats keep the first "decent size" halibut they catch and then continue fishing in the hopes of catching a larger one. The definition of a "decent size" fish varies by port, by year, or according to the preferences of individual anglers or charter captains.

Some portion of halibut released alive in the recreational fishery undoubtedly die as a result of stress or injuries sustained from hooking, hook removal, and handling. This halibut discard mortality has not been studied in recreational fisheries, and the mortality rate of released fish has not been rigorously estimated. Although recreational harvest is routinely estimated, the additional removals of halibut due to catch-and-release mortality are not. All significant removals should be included in estimation of exploitable biomass and should be taken into account when formulating harvest strategies.

Halibut abundance and exploitable biomass are estimated by the International Pacific Halibut Commission (IPHC) using an analytical stock assessment model (Clark and Hare 2006). The IPHC harvest strategy is to harvest at a fixed exploitation rate as long as the stock is above a threshold biomass. Commercial fishery catch limits are derived by deducting non-commercial removals from the constant exploitation yield (CEY), which is the total allowable removals under the target exploitation rate. So far, discard mortality in the recreational fishery has not been included in the removals for estimation of exploitable biomass and has not been deducted from the CEY with other non-commercial removals. The IPHC has expressed intent to explicitly account for sport fishery discards in the assessment model and apportioning of the CEY.

Commercial, recreational, and subsistence halibut fisheries are managed by the IPHC, North Pacific Fishery Management Council (NPFMC), and National Marine Fisheries Service (NMFS). So far assessment and management have been implemented by IPHC Regulatory Area (Figure 1). The NPFMC established guideline harvest levels (GHLs) for the charter boat fishery in IPHC Areas 2C and 3A that became effective in September 2003. These GHLs were set at 125% of the 1995-1999 charter harvests (in pounds net weight) and did not include release mortality. The GHL by definition refers to the harvest (retention) of halibut in the charter fishery (50 CFR.61).

While the IPHC and NMFS have collected data from the commercial fishery, the Alaska Department of Fish and Game (ADF&G) has taken the lead role in providing estimates of recreational harvest as well as the biological characteristics of that harvest. Halibut harvest is estimated in numbers of fish through the Alaska Statewide Sport Fish Survey, or statewide harvest survey (SWHS). The SWHS is a mail survey of a random sample of households containing sport fishing license holders (e.g., Jennings et al. 2006). This survey has provided estimates of halibut (and other species) harvest since 1977 and total halibut catch (harvest plus released fish) since 1990. ADF&G also collects size data to estimate the average weight, size composition, and other statistics from the recreational harvest through marine fishery monitoring programs in Southeast and Southcentral Alaska. Length measurements used to estimate average net weight of the recreational harvest[1] have been collected at varying levels of intensity and at selected ports since as early as 1980 in Juneau. ADF&G first collected length data in Cook Inlet in 1986. Length data has been collected in a fairly consistent manner at major ports in both regulatory areas since the early 1990s. Adequate length data are available to describe the harvest by user group (charter versus non-charter) in Area 2C since 1998 and in Area 3A since 1994. There is no program in place to obtain length data from halibut released in charter or non-charter fisheries.

There have been previous attempts to quantify recreational discard mortality. Both ADF&G and the IPHC provided the first estimates of discard mortality in the charter fishery for the charter IFQ/moratorium analysis (NPFMC 2001, pages 145-147). The ADF&G estimates assumed a discard mortality rate of 5% and average net weight of 4.9 pounds, corresponding to an average length of 25 inches. The IPHC assumed a discard mortality rate of 10% and average weight equal to that of the harvest, but acknowledged that it was "quite probable" that discarded halibut were smaller than retained fish due to highgrading. Halibut release mortality was also calculated in numbers of fish for Area 3A for the years 1995-1999 (Meyer 2003) and 2000-2002 (Meyer 2006). In both cases a 3.5% mortality rate was assumed, resulting in estimates of catch-and-release mortality that were about 3% of the estimated harvest. Most recently, ADF&G was asked to provide an estimate of the discard mortality rate in the Area 2C charter fishery for the NPFMC analysis of management measures in the Area 2C fishery. The discard mortality rate was estimated at about 5% based on estimates of the proportions of hook types used and assumed mortality rates for each hook type (NPFMC 2007, Appendix II). Because there were no data available on hook types used in the fishery, those estimates were derived using information provided by charter operators and ADF&G staff throughout Southeast Alaska. This discard mortality rate was suggested as an interim value for the analysis pending a more comprehensive evaluation of discard mortality in charter and non-charter fisheries in Area 2C and Area 3A.

This report, therefore, represents the next step in the evaluation of recreational fishery discards in IPHC Areas 2C and 3A. It follows the same basic approach used for the Area 2C mortality rate but uses data collected in 2007 on the proportions of halibut released by each hook type. It also estimates discard mortality by weight back to the year 1995 using the best available data on numbers of fish released. This is a work in progress, and the estimates of mortality rates and total discard mortality will likely be revised and updated as additional information becomes available and suggestions are made for improvement.

OBJECTIVES

The goal of this paper was to estimate discard mortality by charter and non-charter sport fisheries in IPHC Areas 2C and 3A for the period 1995-2006. This required several steps:

1. Summarize available information on the numbers of halibut released in charter and non-charter fisheries.

[1] Net weight is defined as the headed and gutted weight, where round weight = 1.33 net weight. Weights are predicted from fork length L using: Net Wt (lb) = $6.921\times10^{-6}\ L(cm)^{3.24}$ (Clark 1992).

2. Determine discard mortality rates based on available data on hook types used in the sport fishery, and
3. Use available data on the weight composition of the harvest to model the weight composition and average weight of released fish.

METHODS

Both IPHC Regulatory Areas 2C and 3A are divided for sport fishery calculations into a number of subareas. In most cases these subareas follow reporting areas used by the SWHS (SWHS areas). In Area 3A some of the SWHS areas are redefined to form subareas more closely aligned with management of state fisheries, port sampling, and the distribution of the respective fishing fleets. For this document these subareas will be referred to as SWHS areas. Although the published SWHS reports do not summarize data by these custom subareas in Area 3A, unpublished estimates are provided to staff for analysis. Table 1 lists the SWHS areas in each IPHC area and the corresponding ports that are sampled for estimates of mean weight and other indices.

Discard mortality was defined as the total weight of halibut that are released in the sport fishery and subsequently die as a result of stress or injuries sustained during capture and handling. Discard mortality (D, in pounds net weight) was estimated each year by user group (g) as the product of the number of fish released (R), the discard mortality rate (DMR), and the average weight of released fish ($\bar{w}$):

$$D_g = R_g \; DMR_g \; \bar{w}_g \, . \tag{1}$$

The data sources and rationale for developing these components are in the following sections.

NUMBERS OF FISH RELEASED

The most comprehensive data source for estimates of numbers of halibut released is the SWHS. Survey questionnaires request the numbers of halibut caught (catch) and the number kept (harvest), with the difference being the number released. Catch data has only been requested since 1990, and estimates have been broken down by charter and non-charter only since 1995. Therefore, estimates of discard mortality are only computed in this report for the years 1995-2006. The variance of catch and harvest are normally obtained by bootstrapping. Variance of the release component is not routinely calculated, but for this report the variances for 2003-2005 were obtained by bootstrapping and variances for 1996-2002 were imputed (Appendix 1). Loss of data prevented calculation of variances for 1995, and variances for 2006 have not yet been calculated.

There are two additional sources of data on the numbers of released halibut. The numbers of halibut released were required to be reported in charter logbooks in 1998-2001 and in 2006. In addition, charter captains and private boat anglers are interviewed through ADF&G fishery monitoring programs in Southeast and Southcentral Alaska to obtain the numbers of fish kept and released on a vessel-trip basis. The SWHS estimates were chosen over these other sources because the SWHS estimates are used by the IPHC for stock assessment, they were the basis for calculation of GHLs, and they are available for both the charter and non-charter (private) sectors for a continuous time series.

Although the SWHS estimates of released fish were chosen for discard calculations, estimates of the discard proportions (fraction of halibut caught that were released) from the SWHS, fishery monitoring interviews, and logbook were compared to evaluate reporting bias. The rationale for this comparison was twofold. First, numbers of fish kept and released that were reported at the conclusion of a fishing trip were thought to be less subject to recall bias than numbers reported in the mail survey after the fishing season. Second, there is a potential for differences because on-site interviews were conducted with charter operators while the mail survey collected information from the clients directly.

DISCARD MORTALITY RATE

There have been no studies to explicitly estimate the DMR of halibut caught and released in recreational fisheries. Catch and release mortality has been studied for a number of other marine species. Some factors that have been shown to have an effect on the estimate of the mortality rate include the type of hook used, where the hook is embedded in the fish, terminal gear (artificial or bait) used, length of time the fish is played, water temperature, handling time in and out of water, release method, species-specific physiology, and the term of the mortality assessment (Bartholomew and Bohnsack 2005, Muoneke and Childress 1994). Selection of working values for the DMR should integrate as many of these factors as possible.

Gear type is believed to be a primary factor in the mortality of released halibut. The majority of halibut are caught on circle hooks baited with herring, octopus, squid, cod, or salmon. Circle hooks are used widely in the charter fishery because they require little or no special skill on the part of the angler to hook a halibut. Several studies have shown that hooking mortality is highly dependent on the hooking location, and deeply hooked fish have much higher mortality rates (e.g., Aguilar 2003, Cooke and Suski 2004, Diodati and Richards 1996, Lukacovic and Uphoff 2002, Malchoff et al. 2002, Murphy et al. 1995). Circle hooks are less likely to become lodged deep in the fish than J hooks. Most fish caught on circle hooks are hooked in the lip and suffer minor injuries with little bleeding (Aalbers et al. 2004, Aguilar 2003, Bacheler and Buckel 2004, Cooke and Suski 2004, Prince et al. 2002, Skomal et al. 2002, Zimmerman and Bochenek 2002). Circle hooks may also sometimes penetrate the eyes of small halibut. Although there are no data from the sport fishery, Kaimmer and Trumble (1998) reported that 1.3% of 5,255 halibut less than 82 cm in length that were caught on longline gear using circle hooks were hooked in the eye.

Even though circle hooks are the primary gear used, a variety of other hook types are used. Some charter operators set clients up with J hooks when targeting halibut, especially if the clients are more experienced or prefer to actively set the hook. Halibut are also caught to a lesser degree on leadhead jigs, or solid-body jigs (e.g. Diamond Jig®) with single J hooks or treble hooks. In addition, halibut are caught by anglers mooching for salmon with baited J hooks or trolling for salmon using baited J hooks or treble hooks or artificial lures with salmon-type J hooks. Because leadhead jigs are actively fished, rather than soaked like bait, they probably aren't often hooked deeply. Jigs sometimes penetrate blood vessels in the mouth or eyes of small halibut, and may also penetrate the gut cavity when hooked in the body of the fish.

Before 2007 there was very little data on the gear types or hook types used in the recreational fishery. The percentages of effort and halibut harvest were estimated by terminal gear type at four Southcentral Alaska ports of Kodiak, Homer, Seward, and Valdez in 1993. The terminal gear types were bait, bait + other, and other, where "other" included jig, troll, lure, and fly. At that time, bait accounted for 67-98% of the effort and 70-99% of the harvest among the four ports, but no data were collected on hook type (Meyer 1994). To address this need for hook type information, private anglers and charter skippers interviewed in 2007 for ADF&G fishery monitoring programs in Southeast and Southcentral Alaska were asked how many halibut they released on circle hooks versus all other hook types. Anglers were also asked what species they were targeting, and these were grouped into three categories: bottomfish (including any combination of halibut, rockfish, lingcod, etc.), salmon, or both. Anglers targeting salmon sharks in Area 3A were excluded from the data. The proportions of halibut released on each hook type were calculated for each target category and weighted by an assumed mortality rate for each hook type to derive the overall mortality rate for each port. At the time of the analysis these data were available for all ports through at least August 12 in Area 2C and August 11 in Area 3A.

The mortality rate was calculated for each user group, port, and target category from

$$m_{gpt} = \left(C_{gpt} m_C\right) + \left(O_{gpt} m_O\right), \tag{2}$$

where C_{gpt} = the assumed proportion of halibut released from circle hooks in by user group *g* at port *p* for target category *t*,

m_C = the assumed mortality rate for circle hooks,

O_{gat} = the assumed proportion of halibut released from other hook types by user group *g* at port *p* for target category *t*, and

m_O = the assumed mortality rate for other hook types.

The overall mortality rate for each user group and port was then calculated as a weighted mean of the mortality rates for all *t* target categories:

$$m_{gp} = \sum_t r_{gpt} m_{gpt} , \quad (3)$$

where r_{gpt} = the proportion of halibut released by user group *g* at port *p* for target category *t* $\left(\sum r_{gpt} = 1\right)$, and

m_{gpt} = the mortality rate for halibut released by user group *g* at port *p* for target category *t*.

Considering that hook use data were only available for part of the 2007 season, that the proportions of fish released on each hook type in each target category vary annually, it wasn't prudent to assume that the calculated rates were consistent from year to year. For each IPHC area, the overall discard mortality rate for each user group was estimated as the weighted mean of the mortality rates for each port:

$$DMR_g = \sum_p r_{gp} m_{gp} , \quad (4)$$

where r_{gp} was the proportion of halibut released by user group *g* applied to port *p*. Because these port data were now expanded to entire IPHC areas, the values for r_{gp} were actually the average proportions of released fish in each SWHS area during the last three years (2004-2006). The calculated DMR values were rounded up to reflect uncertainty in the information. Because of the lack of data and subjectivity involved, no attempt was made to estimate the variances of the chosen mortality rates.

The assumed mortality rates for circle hooks and other hook types were selected after a review of previous estimates for halibut and other species in the literature. The IPHC currently assumes an overall discard mortality rate of 16% for sublegal-size (under 81 cm or 32 in) halibut released in the halibut longline fishery (Gilroy 2007). Virtually all halibut caught in the commercial fishery are caught on circle hooks. The 16% rate was selected because that was the rate for the open access sablefish fishery before implementation of individual fishery quotas (IFQs). It was believed that participants in this fishery at the time operated at a pace similar to the halibut IFQ fishery nowadays (G. Williams, IPHC, personal communication). The 16% rate was derived from assumed discard mortality rates applied to observer data on the proportion of halibut discarded in each of three condition codes. This is similar to the 13% rate estimated for Atlantic halibut *Hippoglossus hippoglossus* under 81 cm caught on circle hooks (Neilson et al. 1989). Kaimmer and Trumble (1998) classified injuries and condition of halibut caught on longline gear, and estimated mortality rates for each condition code based on tag return rates relative to fish that of fish released in excellent condition. The assumed an excellent condition rate of 3.5% based on a study by Peltonen (1969). Peltonen evaluated the mortality of tagged halibut caught on longline gear using J-hooks, held on board in live boxes in groups of 10-36 fish for 22-15 hours, then transferred to live pens in the ocean and held for an additional 14 days. Considering high water temperatures and "poor experimental procedure," Peltonen (1969) concluded that the mortality rate was between 2 and 5 percent, which led to Kaimmer and Trumble's (1998) choice of the 3.5% midpoint.

Although there are no data on hooking injuries or the condition of fish released in the halibut sport fishery, the mortality rate for halibut caught on circle hooks in the sport fishery and released in excellent condition is arguably lower than the 3.5% value assumed by Kaimmer and Trumble (1998) for fish caught on longline gear. Halibut released in the sport fishery, most of which are small fish, are typically on the line for a matter of minutes. Large fish may be fought for tens of minutes. By comparison, longline-caught fish may be on the line for up to 10-12 hours. There is no stress associated with an extended holding period such as that used by Peltonen (1969). Sport-caught fish would be expected to have less lactic acid buildup, less exposure to sand fleas, and be better able to maintain position in strong currents and avoid predators following release. Most fish are released outboard of the boat, usually by shaking the fish off the hook while maintaining downward pressure on the leader. Not all halibut are released in excellent condition, however. Large halibut may require longer handling times during release, especially by less experienced private boat anglers. Some small halibut are likely brought on board to be unhooked. While this additional handling may affect survival, Davis and Schreck (2005) found no significant mortality of age-1 (17-31 cm) and age-2 (40-50 cm) halibut exposed to air for less than 40 or 60 minutes (respectively). Balancing the short playing time and generally small size of the fish against the uncertainty in handling and condition of released fish, a mortality rate of 3.5% was chosen for halibut caught on circle hooks.

The mortality rate for all other hook types was selected after review of hooking mortality studies for other marine species. Salmonids were excluded because they generally had much higher mortality rates. Estimates of hooking mortality for "other" hook types were highly variable, ranging from 1.7% to 33.5%, but most rates for temperate water species were below 10% (Table 2). A mortality rate of 10% was therefore adopted for "other" hook types. The lack of information specific to this species and fishery justifies use of a conservative rate.

Another factor to consider was the effect of repeated catch-and-release of individual fish on the mortality rate. If recapture events are far enough apart that there are no cumulative effects on the probability of death, the assumed mortality rate does not have to be adjusted (see example in Appendix 2). However, if there are cumulative effects that increase the probability of death with successive catch and release events, the mortality rate must be adjusted. The amount of adjustment depends on the probability of fish being recaptured multiple times and the degree to which the mortality rate increases upon successive captures. For example, if the probability of recapture was 5%, and the mortality rate was 5% and doubled with each successive capture, then after three events (original capture plus two recaptures) the adjusted mortality rate that should be multiplied by the number of released fish to correctly predict discard mortality would be 5.27% (Appendix 2). There are no estimates available of the multiple recapture distribution or the effect of multiple catch-and-release events on the mortality rate for sport fisheries in Area 2C or Area 3A. Charter operators do report catching fish that appear to have recently been released, especially when the fleet is concentrated in a relatively small area. This scenario suggests that the effect of multiple recaptures should be taken into account in the choice of the mortality rate.

AVERAGE WEIGHT OF DISCARDED HALIBUT

There are no data available on the sizes of halibut released in the recreational fishery. Stock assessment scientists often assume that the average weight of released fish is the same as the average weight of retained fish. Although this is conservative from a stock conservation standpoint, there may be other information from the fishery that can be used to make deductions regarding the likely range of average weight. For example, in fisheries with minimum size limits, most of the released fish are under the minimum. Although the recreational halibut fishery in Alaska does not have minimum size limits, anglers catch fish of a wide range of sizes, but generally prefer to keep larger fish. In some cases, anglers may not be successful in catching a larger fish and may end up keeping a halibut that is smaller than some of the fish they released. In other instances, large halibut may be released because of angler perceptions of poorer meat quality, because anglers feel the large females should be protected for spawning, or because

the angler already has enough halibut meat and prefers a smaller fish. Therefore, a substantial amount of overlap would be expected in the size distributions of halibut kept and released.

This paper derives likely size distributions and average weight of released fish from a function representing the proportion of fish retained from the catch in each weight class. Without any size data on halibut released in the recreational fishery, the shape of the function was unknown. The probability of discarding a fish of a given size or age is usually modeled in commercial fisheries using a logistic function (Borges et al. 2006, Punt et al. 2006, Palsson 2003). The logistic function is commonly used to model gear selectivity, maturity, and other size-based binary outcomes. For this analysis the proportion of halibut caught that were kept (or the selective retention s_w) was modeled as a function of weight (w) in the sport fishery using

$$s_w = \frac{s_{max}}{1 + e^{-\kappa(w - w50\%)}}, \tag{5}$$

where s_{max} = the asymptotic, or maximum proportion kept, κ = the curvature parameter, and $w50\%$ = the inflection point, or the weight at which $s_w = ½\ s_{max}$. The parameter s_{max} was assumed to equal 0.95 to reflect that a small proportion of large halibut are released (in this case 1 in 20). Some anglers release large halibut either because they believe conservation of large females will increase future recruitment, because they prefer smaller fish for filleting and food quality, or because they already have enough halibut meat for the season. In addition, the Homer halibut derby offers cash drawing prizes for anglers with derby tickets who release halibut over 80 lb (round wt).

The logistic model was applied to 2006 weight-frequency distributions for each IPHC area and user group binned in 1-lb (net weight) increments. The catch in each weight class was predicted by $C_w = H_w / s_w$, where H_w = the estimated harvest in each weight class (SWHS estimate apportioned by the weight composition from sampling). The number of fish released in each weight class R_w was obtained from $R_w = C_w – H_w$.

Lacking size data from released fish, MS Excel Solver® was used to find the parameters κ and $s50\%$ for which the number of released fish summed over all weight classes equaled the SWHS estimate of released fish. Attempts were made to force the model through three alternative values of s_4, the proportion of 4-lb (60 cm) fish caught that were kept. This size class was arbitrarily chosen to represent small fish from the lower end of the retention curve. The values s_4 = 0.10, 0.20, and 0.30 were felt to capture the likely ranges in both IPHC areas, but other values had to be used to obtain fits (see results). Once a fit was obtained that satisfied the above criteria, average weights of released fish $\overline{w}_{Rel}$ and the ratios $\overline{w}_{Rel} / \overline{w}_{Harvest}$ were calculated from the predicted weight-frequency distributions of released fish. From this range of outcomes a single ratio was chosen and applied to obtain $\overline{w}_{Rel}$ for use in equation 1. To summarize, the objective of modeling was to find a realistic value for the average weights of released fish assuming the decision to retain fish is a logistic function of fish size, s_{max} = 0.95, and the SWHS estimates of numbers of released fish are accurate.

RESULTS

NUMBERS OF RELEASED HALIBUT

A substantial portion of the halibut caught in the sport fisheries in Areas 2C and 3A were released (Figure 1). The SWHS estimates of released fish ranged from 24,000-59,000 halibut annually in the Area 2C charter fishery from 1995-2006 (Table 3). Releases in the Area 2C private fishery ranged from 18,000-38,000 fish. In Area 3A, estimates ranged from 101,000-180,000 halibut released annually in the charter fishery and 66,000-110,000 in the private fishery.

Precision of the release estimates was lower (larger standard errors) and more variable from year to year in Area 2C than in Area 3A (Figure 1). The CVs of the Area 2C release estimates ranged from 7-13% for the charter fishery and 11-17% for the private fishery. The Area 3A CVs ranged from 4-5% for the charter fishery and 6-9% for the private fishery.

The released halibut accounted for 31%-44% of the halibut caught on charter boats and 30%-40% of the private boat catch. Area 3A charter anglers released 43%-52% of the catch while private anglers released 42%-48%. The estimated proportions of halibut released were similar between the SWHS, the on-site interviews, and the charter logbook. The release proportions for the overall fishery (charter and private) from the SWHS were usually within 0.10 of the interview estimates in Area 2C (Figure 2). In Area 3A, estimates from the two sources were generally within 0.03 each year, with a maximum difference of 0.06 in 2006. Estimates of the release proportion from logbooks also tracked closely with estimates for the charter fishery from the SWHS and interviews, varying no more than 0.10 in either area.

DISCARD MORTALITY RATE

Discard mortality rates varied considerably among ports due to differences in the proportions of fish released from each hook type. In Area 2C, estimated DMRs ranged from 3.5%-7.2% in the charter fishery and from 3.8%-9.5% in the private fishery (Table 4). The proportions of halibut released from circle hooks ranged from 43-99% in the charter fishery and from 8-95% in the private fishery. The proportions of halibut released from other hooks was consistently higher in the private fishery.

Estimated DMRs in Area 3A ranged from 3.5%-6.5% in the charter fishery and 3.5%-6.6% in the private boat fishery (Table 5). Circle hooks accounted for the majority of halibut released in the charter and private fisheries. Circle hooks accounted for 93% to nearly 100% of released halibut in the charter fisheries in Central Cook Inlet, Homer, Seward, Valdez, and Yakutat. Use of other hook types was more prevalent in the private boat fishery. The proportion of released halibut from other hook types ranged as high as 48% at Kodiak and Whittier.

Overall mortality rates were slightly lower in Area 3A than in Area 2C due to the higher proportions of fish released using circle hooks. The weighted DMR estimates in Area 2C were 5.1% for charters and 5.6% for private anglers (Table 6). Estimated DMRs for Area 3A 3.9% for charter and 4.5% for private anglers. The final choice of mortality rates considered variation from year to year in the numbers of fish released, the undocumented variation in hook use from year to year, and increases in mortality due to the cumulative effects of multiple recaptures. The final assumed mortality rates were:

Area 2C	Charter	6 %
	Private	7%
Area 3A	Charter	5%
	Private	6%

AVERAGE WEIGHT

The minimum values for s_4 that allowed fit of the selective retention model were 0.24 for Area 2C charter data, 0.28 for Area 2C private data, 0.10 for Area 3A charter data, and 0.16 for Area 3A private data. Therefore the 2C models were fit to three alternative values of s_4 ranging from the minimum up to 0.40 in Area 2C, and from the minimum up to 0.30 in Area 3A.

For Area 2C, the predicted average weights from the three alternative fits ranged from 5.86-8.38 lb for the charter fishery and 5.21-7.25 lb for the private fishery (Table 7). The ratio $\overline{w}_{Rel} / \overline{w}_{Harvest}$ was sensitive to the choice of s_4, ranging from 29%-42% for the charter fishery and 37%-51% for the private fishery. The results for $s_4 = 0.30$ were chosen for calculating discard mortality. The fits to $s_4 = 0.24$ were judged to produce releases of too many small fish, especially in the 0-1 lb category, and the fits to $s_4 = 0.40$

appeared to produce too high a probability of retaining halibut weighing under 4 lb and too much overlap with the sizes of fish harvested (Figure 3).

For Area 3A, the predicted average weights of released halibut resulting from the three model fits to assumed values of s_4 ranged from 9.15-11.78 lb for the charter fishery and 5.33-7.85 lb for the private fishery (Table 7). The average weights of released fish represented 51%-66% of the charter harvest average weight and 37%-54% of the private harvest average weight. Of the alternative model fits, the fits to $s_4 = 0.20$ seemed most reasonable. When the model was fit to $s_4 = 0.10$, it appeared the release of intermediate size (10-15 lb) fish was underestimated, and at $s_4 = 0.30$, the fractions of small fish (under 10%) that were kept seemed unreasonably high and there was more overlap in the size distributions of released and harvested fish than seemed realistic (Figure 4). Therefore, the $\overline{w}_{Rel} / \overline{w}_{Harvest}$ ratios chosen for calculating discard mortality in Area 3A were based on models with $s_4 = 0.20$.

Finally, because the choice of mean weight ratios was highly subjective, the final working values for calculation of discard mortality were rounded to the nearest 5 percentage points:

Area 2C	Charter	35%
	Private	40%
Area 3A	Charter	60%
	Private	45%

TOTAL DISCARD MORTALITY

The predicted average weights of halibut released by Area 2C charter anglers ranged from 6.2-10.2 lb net (8.2-13.6 lb round), while average weights of fish released by private anglers ranged from 5.6-9.1 lb net (7.4-12.1 lb round). These mean weights, combined with the chosen discard mortality rates resulted in estimates of discard mortality ranging from 0.009-0.024 M lb (1,419-3,533 fish) in the charter fishery, and 0.009-0.020 M lb (1,281-2,679 fish) in the private fishery (Table 8). Discard mortality appears to be small relative to the harvest, with total removals only about 1.0-1.6% higher than the charter harvest and 1.2-1.9% higher than the private harvest (by weight).

Similar patterns were seen in Area 3A, although the magnitude of discard mortality was higher because more fish were released and the average weight ratio of released to harvested fish was greater. Predicted average weights of released fish ranged from 10.7-13.4 lb net (14.2-17.8 lb round) in the charter fishery and 6.5-7.9 lb net (8.6-10.5 lb round) in the private fishery. Estimates of released fish that died ranged from 0.058-0.110 M lb (5,049-8,988 fish) per year in the charter fishery and from about 0.029 -0.052 M lb (3,946-6,594 fish) per year in the private fishery (Table 8). Discard mortality represented another 2.2%-3.2% of charter removals and an additional 1.9%-2.5% of private removals, relative to the harvest.

DISCUSSION

This paper attempted to obtain likely estimates of halibut discard mortality in Alaska recreational fisheries using available estimates of the number of fish released, hook use, and size composition of the harvest. These data were combined with what were felt to be reasonable assumptions regarding mortality rates by hook type and the probability of retention by size. Estimates were rounded up to reflect uncertainty due to a number of factors.

Despite significant rounding up of calculated mortality rates, the analysis appears to demonstrate that the discard mortality rate is probably fairly low, probably under 10%, due to the widespread use of circle hooks in the sport fishery. The 2007 data on numbers of fish released by hook type reflect anecdotal reports from charter operators and ADF&G staff that use of J-hooks varies by port, and is generally higher among private anglers. The mortality rate was assumed to be equal for released fish of all sizes.

While this may not be true, it was necessary because there were no size data on released fish, and because mortality rates estimated for halibut and other species are generally not estimated by size.

There were some weaknesses in the modeling of retention probability. First, the retention probability curve was fit to harvest composition data, so it was unable to predict any released fish smaller than the smallest harvested fish. This was not felt to introduce a large error because released fish that are smaller than the smallest harvested fish would have little influence on the overall average weight. Second, the model was fit under the assumption that the predicted number of released fish equaled the SWHS estimate of released fish. There is no guarantee that the SWHS estimates are accurate, but this was assumed simply to produce realistic estimates. A curve fit to actual size data from released fish might in fact predict numbers of released fish that deviate from the SWHS estimates. It's also possible that a logistic model would fit the data poorly. Finally, the retention curves were fit only to size composition data from 2006. The overall harvest composition data for Areas 2C and 3A can change from year to year as a function of fish recruitment, changes in the spatial distribution of the fishery, and other factors that affect catchability of fish by size. These curves should also be fit to data from earlier years to describe the effect of annual variability in harvest composition on the estimates of $\overline{w}_{Rel} / \overline{w}_{Harvest}$.

Even though the retention of halibut by size was modeled without any data, the results suggest that it may be overly conservative to assume that discards and harvested fish have the same average weight. Even under severe assumptions regarding the retention of 60-cm fish, the average weight of released fish was substantially lower than the average weight in the harvest.

Accurate estimation of discard mortality would probably benefit most from collection of size data on discarded fish. Given the high variability in the average weights among ports and vessel trips, broad coverage and random, or at least representative, sampling of vessels would be required. Anything less than a properly designed and implemented program could produce badly biased estimates. Sampling the private boat fishery might be especially problematic. There may, however, be value in limited sampling of selected aspects of the fishery in order to evaluate assumptions, similar to the manner in which hook use data contributes to estimation of mortality rates.

As stated earlier, this is a work in progress, and will be revised and updated to reflect new information as well as suggestions for improvement.

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Table 1. SWHS areas and corresponding ports sampled for estimation of mean weight and other fishery statistics in IPHC areas 2C and 3A.

IPHC Area	SWHS Area	Sampled Ports
Area 2C	Ketchikan	Ketchikan
	Prince of Wales	Craig, Klawock
	Kake, Petersburg, Wrangell, Stikine	Petersburg, Wrangell
	Sitka	Sitka
	Juneau	Juneau
	Haines-Skagway	None (substitute Juneau data)
	Glacier Bay	Elfin Cove and Gustavus
Area 3A	Yakutat	Yakutat
	Eastern PWS	Valdez
	Western PWS	Whittier
	North Gulf Coast	Seward
	Lower Cook Inlet (LCI)	Homer
	Central Cook Inlet (CCI)	Deep Creek and Anchor Point beaches
	Kodiak	City of Kodiak

Table 2. Estimated mortality rates from circle and J-hook types in several species of marine fish.

Species	Gear Type	Mortality Rate (%) Circle Hook	J Hook	Mixed Hook Types	Reference
Atlantic halibut	Longline	13			Neilson et al. 1989
Pacific halibut	Longline		2-5		Peltonen 1969
Striped bass	Rod and reel			5.06	Lukacovic and Florence 1999
Striped bass	Rod and reel	0.8	9.1		Lukacovic 2000
Striped bass	Rod and reel	1.9	8.7		Lukacovic 2001
Striped bass	Rod and reel	0.8	7.4		Lukacovic 2002
Striped bass	Rod and reel	3	15.5		Caruso 2000
Striped bass	Rod and reel			9.0	Diodati and Richards 1996
Bluefin tuna	Rod and reel	4.0	28.0		Skomal et al. 2002
Red drum	Rod and reel	0	8.5-9.1		Aguilar 2003
Spotted seatrout	Rod and reel		4.6		Murphy et al. 1995
Spotted seatrout	Rod and reel			17.5	Thomas et al. 1997
Red drum	Rod and reel			2.7	Thomas et al. 1997
White seabass	Rod and reel			10	Aalbers et al. 2004
Snook	Rod and reel			2.13	Taylor et al. 2001
Tautog	Rod and reel		1.7		Lucy and Arendt 2002
Tautog	Rod and reel			2.7	Simpson 1999
Black sea bass	Rod and reel			4.7	Bugley and Shepherd 1991
Summer flounder	Rod and reel			9.5	Malchoff et al. 2002
Lingcod	Rod and reel			4.3	Albin and Karpov 1998
Yellowfin bream	Rod and reel		27.8		Broadhurst et al. 2005
Trevally	Rod and reel		2.0		Broadhurst et al. 2005
Snapper	Rod and reel		33.5		Broadhurst et al. 2005
Yellow stripey	Rod and reel			1.76	Diggles and Ernst 1997

Table 3. Estimated numbers of halibut harvested and released in charter and private fisheries in Areas 2C and 3A, 1995-2006 (SWHS data).

	Charter				Private				Total			
Year	Harvest	SE (Harv)	Release	SE Rel)	Harvest	SE (Harv)	Release	SE (Rel)	Harvest	SE (Harv)	Release	SE (Rel)
Area 2C												
1995	49,615	n.d.	32,244	n.d.	39,707	n.d.	23,365	n.d.	89,322	n.d.	55,609	n.d.
1996	53,590	2,296	41,203	2,917	41,307	2,148	19,731	2,210	94,897	3,182	60,934	3,712
1997	51,181	2,303	40,236	3,345	53,205	2,498	33,784	3,654	104,386	3,410	74,020	5,208
1998	54,364	2,550	38,801	3,281	42,580	3,254	21,078	3,294	96,944	4,085	59,879	4,655
1999	52,735	2,508	23,647	2,343	44,301	2,355	22,553	2,599	97,036	3,510	46,200	3,709
2000	57,208	2,584	28,357	3,762	54,432	2,952	34,168	4,752	111,640	3,899	62,525	6,187
2001	66,435	2,643	37,484	2,597	43,519	2,269	18,304	2,301	109,954	3,483	55,788	3,544
2002	64,614	2,729	32,015	2,599	40,199	2,500	19,106	3,214	104,813	3,679	51,121	4,329
2003	73,784	2,995	41,541	3,780	45,697	2,763	25,858	3,165	119,481	4,032	67,399	4,846
2004	84,327	3,397	52,690	4,837	62,989	3,303	37,671	5,128	147,316	4,837	90,361	7,077
2005	102,206	4,074	58,878	5,067	60,364	3,689	38,267	4,798	162,570	5,667	97,145	6,949
2006	90,471	3,471	51,549	n.d.	50,520	2,789	34,091	n.d.	140,991	4,074	85,640	n.d.
Area 3A												
1995	137,843	n.d.	125,633	n.d.	95,206	n.d.	80,994	n.d.	233,049		206,627	n.d.
1996	142,957	3,390	148,578	6,990	108,812	3,638	94,234	5,932	251,769	4,923	242,812	27,022
1997	152,856	3,649	163,524	6,777	119,510	3,897	109,844	6,411	272,366	5,388	273,368	9,327
1998	143,368	3,961	132,385	6,585	105,876	3,573	94,216	6,675	249,244	4,940	226,601	9,103
1999	131,730	3,310	101,066	5,073	99,498	3,514	76,914	6,006	231,228	4,921	177,980	7,825
2000	159,609	3,850	127,716	6,054	128,427	4,717	109,895	10,067	288,036	5,966	237,611	12,208
2001	163,349	4,213	130,503	6,133	90,249	3,792	65,773	5,137	253,598	5,485	196,276	8,051
2002	149,608	5,014	111,150	5,728	93,240	4,039	68,651	6,505	242,848	6,160	179,801	9,135
2003	163,629	4,198	133,855	6,986	118,004	4,993	87,741	6,992	281,633	6,080	221,596	9,283
2004	197,208	4,445	162,927	7,207	134,960	4,687	108,195	6,851	332,168	6,158	271,122	9,356
2005	206,902	4,812	174,040	7,280	127,086	6,011	104,876	9,172	333,988	7,590	278,916	11,124
2006	204,115	5,068	179,765	n.d.	114,887	5,133	85,733	n.d.	319,002	6,725	265,498	n.d.

Table 4. Area 2C data from 2007 interviews showing halibut released by hook type and target category for each user group, and calculation of discard mortality rates (DMRs) by port. Overall DMRs for each port and user listed at right in bold text.

				No. Halibut Released by Hook Type								
Port	DataThru	User	Target	Circle	Other	Total	HaRel%	C%	C DMR	Other%	Oth DMR	DMR
Elfin Cove	8/19/2007	Charter	Btmfish	211	15	226	0.278	0.93	0.035	0.07	0.10	0.039
			Salmon	9	8	17	0.021	0.53	0.035	0.47	0.10	0.066
			Both	496	75	571	0.701	0.87	0.035	0.13	0.10	0.044
			Total	716	98	814	1.000	0.88		0.12		**0.043**
Gustavus	8/19/2007	Charter	Btmfish	2183	4	2187	0.715	1.00	0.035	0.00	0.10	0.035
			Salmon	4	0	4	0.001	1.00	0.035	0.00	0.10	0.035
			Both	841	26	867	0.284	0.97	0.035	0.03	0.10	0.037
			Total	3028	30	3058	1.000	0.99		0.01		**0.036**
Juneau	8/19/2007	Charter	Btmfish	22	0	22	0.220	1.00	0.035	0.00	0.10	0.035
			Salmon	0	1	1	0.010	0.00	0.035	1.00	0.10	0.100
			Both	74	3	77	0.770	0.96	0.035	0.04	0.10	0.038
			Total	96	4	100	1.000	0.96		0.04		**0.038**
Sitka	8/19/2007	Charter	Btmfish	12	14	26	0.060	0.46	0.035	0.54	0.10	0.070
			Salmon	27	23	50	0.115	0.54	0.035	0.46	0.10	0.065
			Both	207	152	359	0.825	0.58	0.035	0.42	0.10	0.063
			Total	246	189	435	1.000	0.56		0.44		**0.063**
Ketchikan	8/12/2007	Charter	Btmfish	10	0	10	0.233	1.00	0.035	0.00	0.10	0.035
			Salmon	0	0	0	0.000	0.00	0.035	0.00	0.10	0.000
			Both	11	22	33	0.767	0.33	0.035	0.67	0.10	0.078
			Total	21	22	43	1.000	0.49		0.51		**0.068**
Craig/Klawock	8/12/2007	Charter	Btmfish	34	0	34	0.047	1.00	0.035	0.00	0.10	0.035
			Salmon	73	72	145	0.199	0.50	0.035	0.50	0.10	0.067
			Both	286	263	549	0.754	0.52	0.035	0.48	0.10	0.066
			Total	393	335	728	1.000	0.54		0.46		**0.065**
Wrangell	8/12/2007	Charter	Btmfish	6	27	33	0.702	0.18	0.035	0.82	0.10	0.088
			Salmon	0	0	0	0.000	0.00	0.035	0.00	0.10	0.000
			Both	14	0	14	0.298	1.00	0.035	0.00	0.10	0.035
			Total	20	27	47	1.000	0.43		0.57		**0.072**
Petersburg	8/12/2007	Charter	Btmfish	601	6	607	0.692	0.99	0.035	0.01	0.10	0.036
			Salmon	0	0	0	0.000	0.00	0.035	0.00	0.10	0.000
			Both	270	0	270	0.308	1.00	0.035	0.00	0.10	0.035
			Total	871	6	877	1.000	0.99		0.01		**0.035**

(continued)

Table 4 (continued).

Port	DataThru	User	Target	No. Halibut Released by Hook Type			HaRel%	C%	C DMR	Other%	Oth DMR	DMR
				Circle	Other	Total						
Elfin Cove	8/19/2007	Private	Btmfish	16	2	18	0.300	0.89	0.035	0.11	0.10	0.042
			Salmon	1	10	11	0.183	0.09	0.035	0.91	0.10	0.094
			Both	26	5	31	0.517	0.84	0.035	0.16	0.10	0.045
			Total	43	17	60	1.000	0.72		0.28		**0.053**
Gustavus	8/19/2007	Private	Btmfish	247	16	263	0.835	0.94	0.035	0.06	0.10	0.039
			Salmon	0	0	0	0.000	0.00	0.035	0.00	0.10	0.000
			Both	52	0	52	0.165	1.00	0.035	0.00	0.10	0.035
			Total	299	16	315	1.000	0.95		0.05		**0.038**
Juneau	8/19/2007	Private	Btmfish	367	171	538	0.653	0.68	0.035	0.32	0.10	0.056
			Salmon	0	48	48	0.058	0.00	0.035	1.00	0.10	0.100
			Both	177	61	238	0.289	0.74	0.035	0.26	0.10	0.052
			Total	544	280	824	1.000	0.66		0.34		**0.057**
Sitka	8/19/2004	Private	Btmfish	35	29	64	0.604	0.55	0.035	0.45	0.10	0.064
			Salmon	10	29	39	0.368	0.26	0.035	0.74	0.10	0.083
			Both	0	3	3	0.028	0.00	0.035	1.00	0.10	0.100
			Total	45	61	106	1.000	0.42		0.58		**0.072**
Ketchikan	8/12/2007	Private	Btmfish	93	52	145	0.694	0.64	0.035	0.36	0.10	0.058
			Salmon	2	12	14	0.067	0.14	0.035	0.86	0.10	0.091
			Both	45	5	50	0.239	0.90	0.035	0.10	0.10	0.042
			Total	140	69	209	1.000	0.67		0.33		**0.056**
Craig/Klawock	8/12/2007	Private	Btmfish	2	12	14	0.059	0.14	0.035	0.86	0.10	0.091
			Salmon	35	26	61	0.255	0.57	0.035	0.43	0.10	0.063
			Both	35	129	164	0.686	0.21	0.035	0.79	0.10	0.086
			Total	72	167	239	1.000	0.30		0.70		**0.080**
Wrangell	8/12/2007	Private	Btmfish	3	16	19	0.528	0.16	0.035	0.84	0.10	0.090
			Salmon	0	3	3	0.083	0.00	0.035	1.00	0.10	0.100
			Both	0	14	14	0.389	0.00	0.035	1.00	0.10	0.100
			Total	3	33	36	1.000	0.08		0.92		**0.095**
Petersburg	8/12/2007	Private	Btmfish	481	108	589	0.888	0.82	0.035	0.18	0.10	0.047
			Salmon	0	1	1	0.002	0.00	0.035	1.00	0.10	0.100
			Both	65	8	73	0.110	0.89	0.035	0.11	0.10	0.042
			Total	546	117	663	1.000	0.82		0.18		**0.046**

Table 5. Area 3A data from 2007 interviews showing halibut released by hook type and target category for each user group, and calculation of discard mortality rates (DMRs) by port. Overall DMRs for each port and user listed at right in bold text.

				No. Halibut Released by Hook Type								
Port	DataThru	User	Target	Circle	Other	Total	HaRel%	C%	C DMR	Other%	Oth DMR	DMR
Deep Cr./ Anchor Pt.	08/11/07	Charter	Btmfish	2886	15	2901	0.660	0.99	0.035	0.01	0.10	0.035
			Salmon	0	0	0	0.000	0.00	0.035	0.00	0.10	0.000
			Both	1497	0	1497	0.340	1.00	0.035	0.00	0.10	0.035
			Total	4383	15	4398	1.000	1.00		0.00		**0.035**
Homer	08/11/07	Charter	Btmfish	4461	90	4551	0.886	0.98	0.035	0.02	0.10	0.036
			Salmon	1	7	8	0.002	0.13	0.035	0.88	0.10	0.092
			Both	420	159	579	0.113	0.73	0.035	0.27	0.10	0.053
			Total	4882	256	5138	1.000	0.95		0.05		**0.038**
Kodiak	08/12/07	Charter	Btmfish	68	14	82	0.293	0.83	0.035	0.17	0.10	0.046
			Salmon	0	4	4	0.014	0.00	0.035	1.00	0.10	0.100
			Both	167	27	194	0.693	0.86	0.035	0.14	0.10	0.044
			Total	235	45	280	1.000	0.84		0.16		**0.045**
Seward	08/11/07	Charter	Btmfish	593	68	661	0.563	0.90	0.035	0.10	0.10	0.042
			Salmon	2	0	2	0.002	1.00	0.035	0.00	0.10	0.035
			Both	503	9	512	0.436	0.98	0.035	0.02	0.10	0.036
			Total	1098	77	1175	1.000	0.93		0.07		**0.039**
Valdez	08/11/07	Charter	Btmfish	376	9	385	0.997	0.98	0.035	0.02	0.10	0.037
			Salmon	0	0	0	0.000	0.00	0.035	0.00	0.10	0.000
			Both	0	1	1	0.003	0.00	0.035	1.00	0.10	0.100
			Total	376	10	386	1.000	0.97		0.03		**0.037**
Whittier	08/19/07	Charter	Btmfish	51	69	120	0.769	0.43	0.035	0.58	0.10	0.072
			Salmon	0	0	0	0.000	0.00	0.035	0.00	0.10	0.000
			Both	33	3	36	0.231	0.92	0.035	0.08	0.10	0.040
			Total	84	72	156	1.000	0.54		0.46		**0.065**
Yakutat	08/12/07	Charter	Btmfish	296	15	311	0.869	0.95	0.035	0.05	0.10	0.038
			Salmon	0	0	0	0.000	0.00	0.035	0.00	0.10	0.000
			Both	46	1	47	0.131	0.98	0.035	0.02	0.10	0.036
			Total	342	16	358	1.000	0.96		0.04		**0.038**

(continued)

Table 5 (continued).

Port	DataThru	User	Target	No. Halibut Released by Hook Type Circle	Other	Total	HaRel%	C%	C DMR	Other%	Oth DMR	DMR
Deep Cr./ Anchor Pt.	08/11/07	Private	Btmfish	1475	7	1482	0.890	1.00	0.035	0.00	0.10	0.035
			Salmon	0	0	0	0.000	0.00	0.035	0.00	0.10	0.000
			Both	183	0	183	0.110	1.00	0.035	0.00	0.10	0.035
			Total	1658	7	1665	1.000	1.00		0.00		**0.035**
Homer	08/11/07	Private	Btmfish	1542	316	1858	0.921	0.83	0.035	0.17	0.10	0.046
			Salmon	0	7	7	0.003	0.00	0.035	1.00	0.10	0.100
			Both	128	25	153	0.076	0.84	0.035	0.16	0.10	0.046
			Total	1670	348	2018	1.000	0.83		0.17		**0.046**
Kodiak	08/12/07	Private	Btmfish	96	68	164	0.577	0.59	0.035	0.41	0.10	0.062
			Salmon	1	17	18	0.063	0.06	0.035	0.94	0.10	0.096
			Both	51	51	102	0.359	0.50	0.035	0.50	0.10	0.068
			Total	148	136	284	1.000	0.52		0.48		**0.066**
Seward	08/11/07	Private	Btmfish	217	31	248	0.813	0.88	0.035	0.13	0.10	0.043
			Salmon	0	0	0	0.000	0.00	0.035	0.00	0.10	0.000
			Both	57	0	57	0.187	1.00	0.035	0.00	0.10	0.035
			Total	274	31	305	1.000	0.90		0.10		**0.042**
Valdez	08/11/07	Private	Btmfish	182	20	202	0.971	0.90	0.035	0.10	0.10	0.041
			Salmon	0	0	0	0.000	0.00	0.035	0.00	0.10	0.000
			Both	6	0	6	0.029	1.00	0.035	0.00	0.10	0.035
			Total	188	20	208	1.000	0.90		0.10		**0.041**
Whittier	08/19/07	Private	Btmfish	197	66	263	0.646	0.75	0.035	0.25	0.10	0.051
			Salmon	0	1	1	0.002	0.00	0.035	1.00	0.10	0.100
			Both	85	58	143	0.351	0.59	0.035	0.41	0.10	0.061
			Total	282	125	407	1.000	0.69		0.31		**0.055**
Yakutat	08/12/07	Private	Btmfish	24	13	37	0.597	0.65	0.035	0.35	0.10	0.058
			Salmon	2	1	3	0.048	0.67	0.035	0.33	0.10	0.057
			Both	6	16	22	0.355	0.27	0.035	0.73	0.10	0.082
			Total	32	30	62	1.000	0.52		0.48		**0.066**

Table 6. Estimation of weighted discard mortality rates (DMR) for charter and private fisheries in areas 2C and 3A. The DMRs for each SWHS area, estimated from 2007 release data by hook type, are weighted by the 2004-2006 average proportions of released fish (pRel) in each SWHS area.

Charter

Area 2C			Area 3A		
SWHS Area	pRel	DMR	SWHS Area	pRel	DMR
Ketchikan	0.070	0.068	Kodiak	0.063	0.045
Craig/Klawock	0.249	0.065	Central Cook Inlet	0.246	0.035
Petersburg/Wrangell	0.078	0.008[a]	Lower Cook Inlet	0.476	0.038
Sitka	0.266	0.063	North Gulf	0.130	0.039
Juneau	0.088	0.038	W PWS	0.037	0.065
Haines-Skagway	0.001	0.038	E PWS	0.040	0.037
Glacier Bay	0.249	0.037[a]	Yakutat	0.008	0.038
Overall weighted rate =		**0.051**	Overall weighted rate =		**0.039**

Private

Area 2C			Area 3A		
SWHS Area	pRel	DMR	SWHS Area	pRel	DMR
Ketchikan	0.119	0.056	Kodiak	0.071	0.066
Craig/Klawock	0.148	0.080	Central Cook Inlet	0.246	0.035
Petersburg/Wrangell	0.126	0.049[a]	Lower Cook Inlet	0.482	0.046
Sitka	0.101	0.072	North Gulf	0.113	0.042
Juneau	0.221	0.057	W PWS	0.039	0.055
Haines-Skagway	0.003	0.057	E PWS	0.048	0.041
Glacier Bay	0.281	0.041[a]	Yakutat	0.002	0.066
Overall weighted rate =		**0.056**	Overall weighted rate =		**0.045**

[a] The DMRs from Petersburg and Wrangell as well as Elfin Cove and Gustavus were weighted by the relative proportions of released fish at each site to arrive at the DMRs for the Petersburg/Wrangell and Glacier Bay SWHS areas.

Table 7. Parameter estimates obtained by fitting selective retention models to 2006 harvest weight frequency data from areas 2C and 3A. Estimates are shown for the curvature parameter κ, inflection point *w50%*, mean weight of released fish $\overline{w}_{Rel}$, and ratio of the mean weight of released fish to the mean weight of harvested fish $\overline{w}_{Rel}/\overline{w}_{Harv}$ for alternative values of s_4, the probability of keeping 4-pound fish.

Area 2C			
Charter	s_4		
	0.24	0.30	0.40
$\kappa =$	0.69	0.37	0.18
w50% =	5.57	6.07	5.81
$\overline{w}_{Rel} =$	5.86	6.97	8.38
$\overline{w}_{Rel}/\overline{w}_{Harvest} =$	0.29	0.35	0.42

Private	s_4		
	0.28	0.30	0.40
$\kappa =$	0.59	0.45	0.19
w50% =	5.49	5.72	5.68
$\overline{w}_{Rel} =$	5.21	5.74	7.25
$\overline{w}_{Rel}/\overline{w}_{Harvest} =$	0.37	0.40	0.51

Area 3A			
Charter	s_4		
	0.10	0.20	0.30
$\kappa =$	0.34	0.19	0.11
w50% =	10.23	10.95	11.12
$\overline{w}_{Rel} =$	9.15	10.63	11.78
$\overline{w}_{Rel}/\overline{w}_{Harvest} =$	0.51	0.59	0.66

Private	s_4		
	0.16	0.20	0.30
$\kappa =$	0.70	0.45	0.23
w50% =	6.27	6.91	7.39
$\overline{w}_{Rel} =$	5.33	6.30	7.85
$\overline{w}_{Rel}/\overline{w}_{Harvest} =$	0.37	0.43	0.54

Table 8. Estimation of discard mortality in the Area 2C and Area 3A charter and private fisheries, 1995-2006, including intermediate values and assumed rates and ratios used in the calculations.

IPHC Area	User	Year	No. Halibut Released	Assumed Mortality Rate	No. Dead Discards	$\bar{w}_{Harvest}$	$\bar{w}_{Rel} / \bar{w}_{Harvest}$	$\bar{w}_{Rel}$	Discard Mortality (M lb)
2C	Charter	1995	32,244	0.06	1,935	19.9	0.35	7.0	0.013
		1996	41,203	0.06	2,472	22.1	0.35	7.8	0.019
		1997	40,236	0.06	2,414	20.2	0.35	7.1	0.017
		1998	38,801	0.06	2,328	29.1	0.35	10.2	0.024
		1999	23,647	0.06	1,419	17.8	0.35	6.2	0.009
		2000	28,357	0.06	1,701	19.8	0.35	6.9	0.012
		2001	37,484	0.06	2,249	18.1	0.35	6.3	0.014
		2002	32,015	0.06	1,921	19.7	0.35	6.9	0.013
		2003	41,541	0.06	2,492	19.1	0.35	6.7	0.017
		2004	52,690	0.06	3,161	20.7	0.35	7.3	0.023
		2005	58,878	0.06	3,533	19.1	0.35	6.7	0.024
		2006	51,549	0.06	3,093	20.0	0.35	7.0	0.022
2C	Private	1995	23,365	0.07	1,636	19.3	0.40	7.7	0.013
		1996	19,731	0.07	1,381	22.8	0.40	9.1	0.013
		1997	33,784	0.07	2,365	21.4	0.40	8.6	0.020
		1998	21,078	0.07	1,475	21.5	0.40	8.6	0.013
		1999	22,553	0.07	1,579	20.4	0.40	8.2	0.013
		2000	34,168	0.07	2,392	20.7	0.40	8.3	0.020
		2001	18,304	0.07	1,281	16.6	0.40	6.6	0.009
		2002	19,106	0.07	1,337	20.3	0.40	8.1	0.011
		2003	25,858	0.07	1,810	18.5	0.40	7.4	0.013
		2004	37,671	0.07	2,637	18.8	0.40	7.5	0.020
		2005	38,267	0.07	2,679	14.0	0.40	5.6	0.015
		2006	34,091	0.07	2,386	14.4	0.40	5.7	0.014
3A	Charter	1995	125,633	0.05	6,282	20.6	0.60	12.4	0.078
		1996	148,578	0.05	7,429	19.7	0.60	11.8	0.088
		1997	163,524	0.05	8,176	22.3	0.60	13.4	0.110
		1998	132,385	0.05	6,619	20.8	0.60	12.5	0.083
		1999	100,976	0.05	5,049	19.2	0.60	11.5	0.058
		2000	127,716	0.05	6,386	19.7	0.60	11.8	0.075
		2001	130,513	0.05	6,526	19.2	0.60	11.5	0.075
		2002	111,149	0.05	5,557	18.2	0.60	10.9	0.061
		2003	133,855	0.05	6,693	20.7	0.60	12.4	0.083
		2004	162,927	0.05	8,146	18.6	0.60	11.2	0.091
		2005	174,040	0.05	8,702	17.8	0.60	10.7	0.093
		2006	179,765	0.05	8,988	17.9	0.60	10.8	0.097
3A	Private	1995	80,994	0.06	4,860	17.5	0.45	7.9	0.038
		1996	94,234	0.06	5,654	17.6	0.45	7.9	0.045
		1997	109,844	0.06	6,591	17.6	0.45	7.9	0.052
		1998	94,216	0.06	5,653	16.2	0.45	7.3	0.041
		1999	76,914	0.06	4,615	17.0	0.45	7.7	0.035
		2000	109,895	0.06	6,594	16.9	0.45	7.6	0.050
		2001	65,763	0.06	3,946	17.1	0.45	7.7	0.030
		2002	68,653	0.06	4,119	15.9	0.45	7.1	0.029
		2003	87,742	0.06	5,265	17.3	0.45	7.8	0.041
		2004	108,195	0.06	6,492	14.4	0.45	6.5	0.042
		2005	104,876	0.06	6,293	15.6	0.45	7.0	0.044
		2006	85,733	0.06	5,144	14.6	0.45	6.6	0.034

Figure 1. Harvest and release of halibut in recreational fisheries in Area 2C (upper block of graphs) and Area 3A (lower block), 1995-2006. Bar charts show the kept and released components of catch by charter and private anglers in each area, and line graphs show SWHS estimates of the numbers of released fish (± 1 SE).

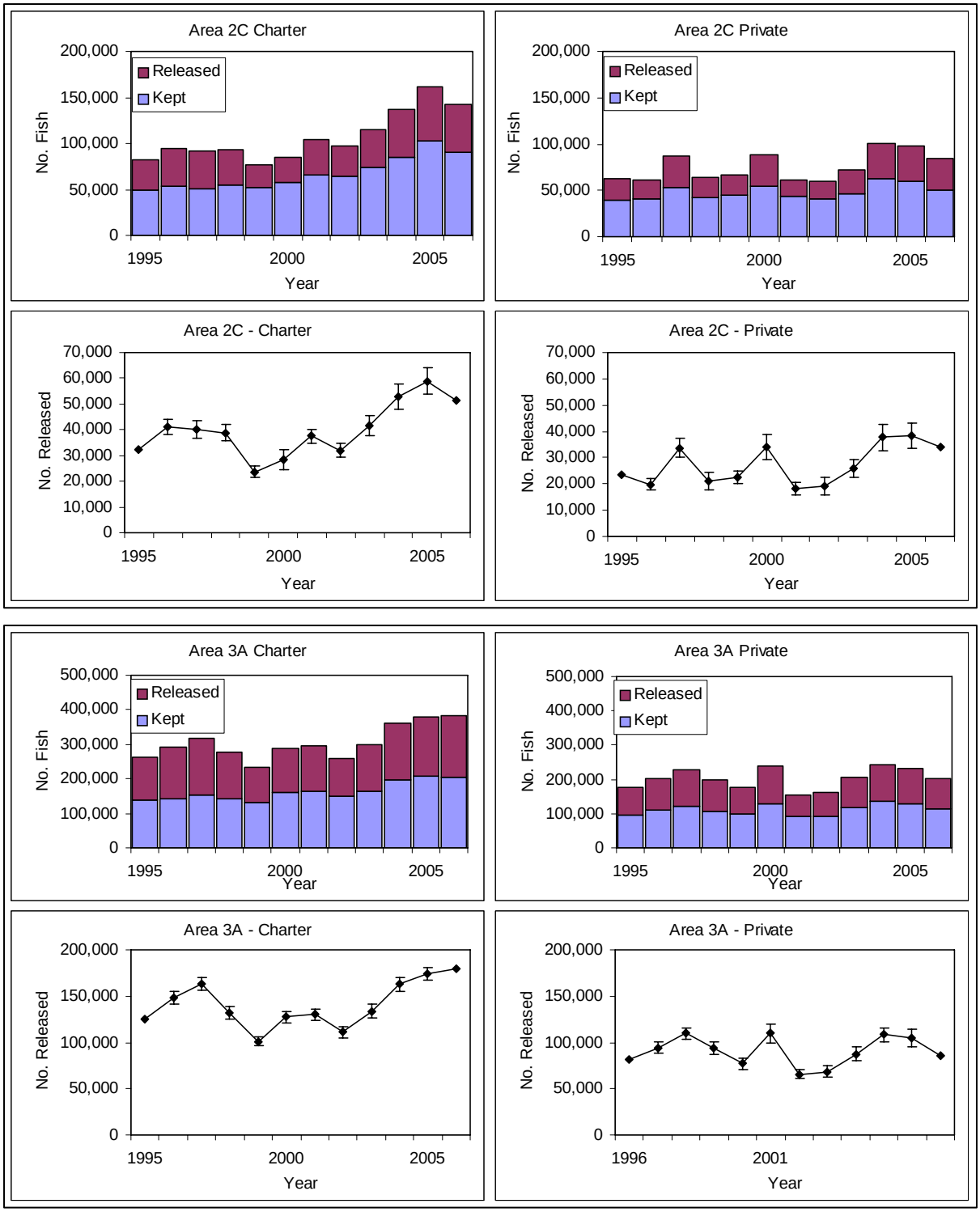


Figure 2. Comparisons of estimates of the proportion of the halibut catch that was released in the overall sport fishery (charter and private) and charter fishery in Area 2C (upper graphs) and Area 3A (lower graphs), 1995-2006.

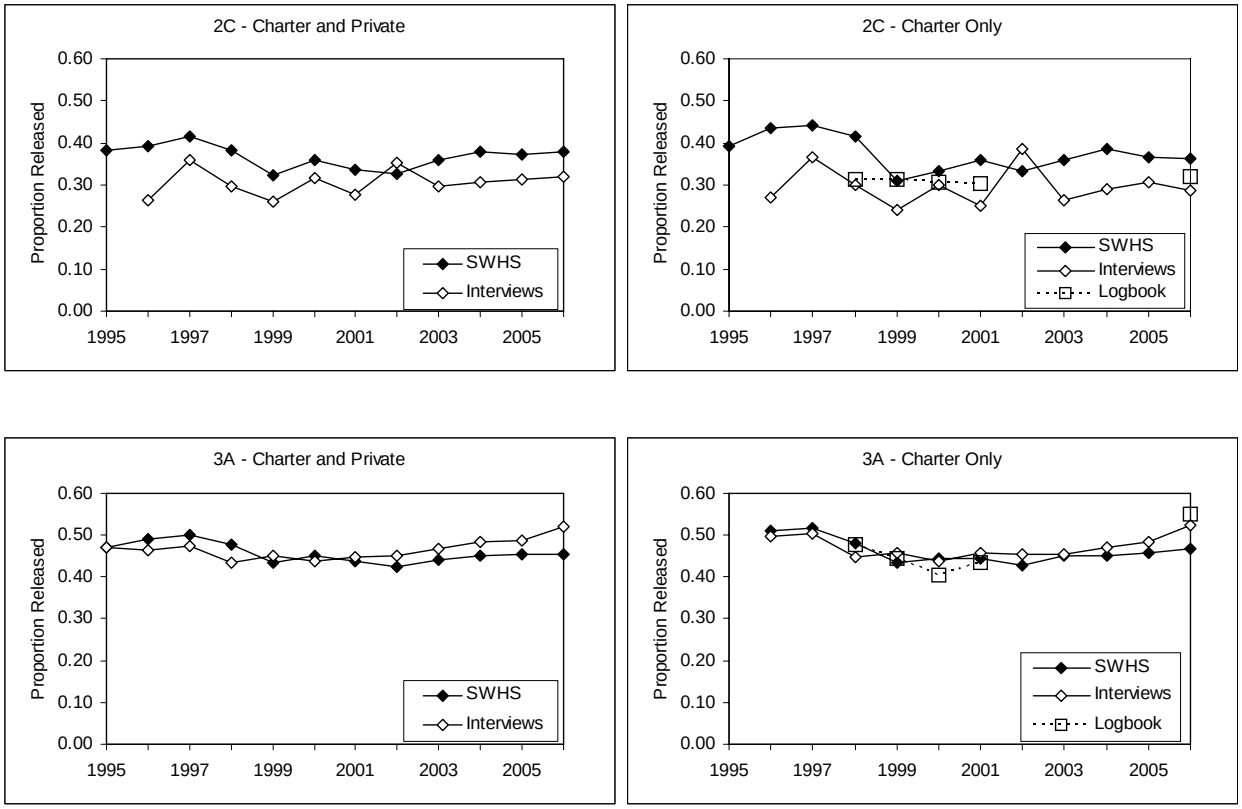


Figure 3. Selectivity for retained fish and modeled weight composition of harvested and released fish in Area 3A, 2006. The charter model was forced through s_4 = 0.24, 0.30, and 0.40 (upper plots), and the private fishery model was forced through s_4 = 0.28, 0.30, and 0.40. All plots are truncated at 60 lb because most of the information was below this point.

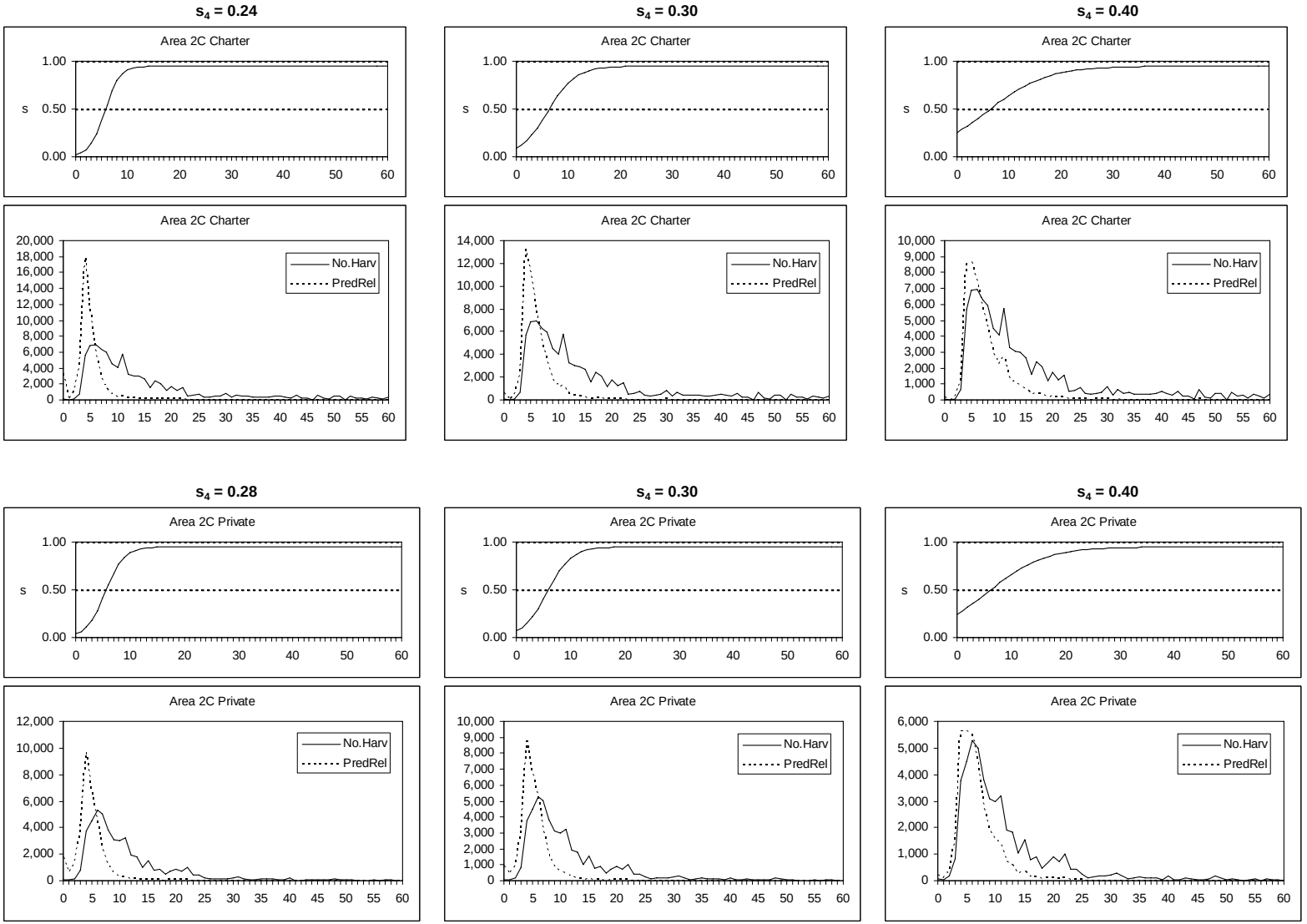


Figure 4. Selectivity for retained fish and modeled weight composition of harvested and released (PredRel) fish in Area 3A, 2006. The charter model was forced through s_4 = 0.10, 0.20, and 0.30 (upper plots), and the private fishery model was forced through s_4 = 0.16, 0.20, and 0.30 (lower plots). All plots are truncated at 60 lb because most of the information was below this point.

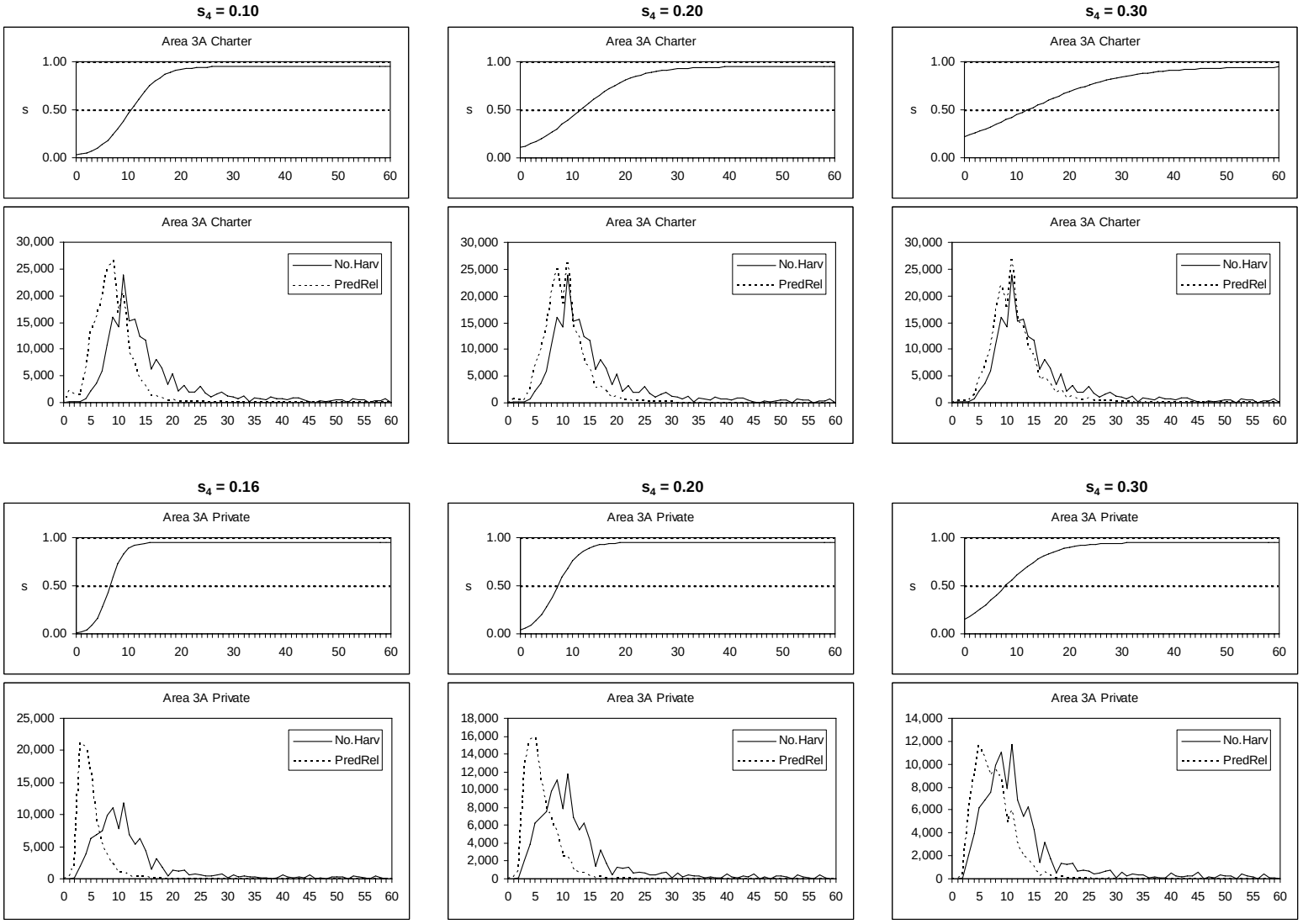
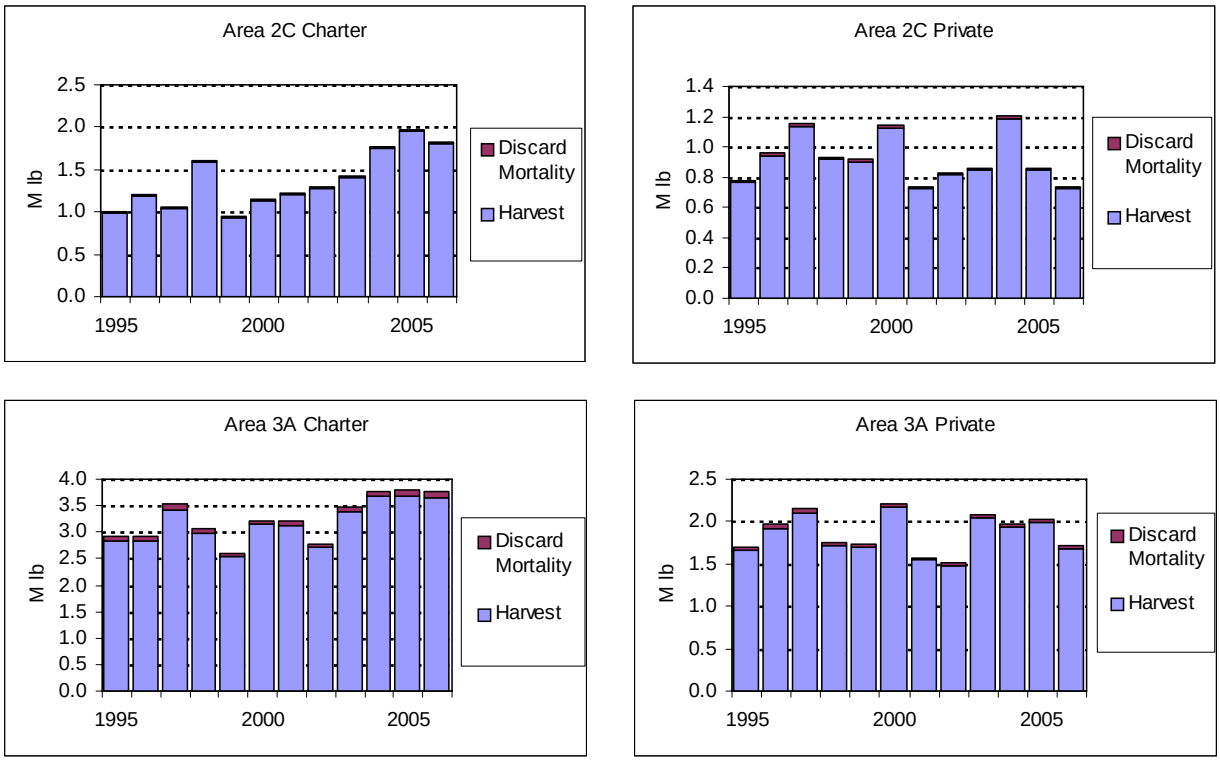


Figure 5. Estimates of recreational halibut harvest and discard mortality in Area 2C and Area 3A charter and private fisheries, 1995-2006.



Appendix 1.–Formulae used to derive the numbers of halibut released and associated variance from the Alaska Sport Fish Survey estimates of numbers caught and numbers harvested.

The number of fish released (R) in each area was the difference between the estimates of catch (C) and harvest (H):

$$R = C - H .$$

The variances of catch and harvest estimates, plus some release estimates for 2003-2005 were obtained by a bootstrap procedure. For other release estimates 1996-2002, the variance was calculated as follows:

$$\hat{V}(\hat{R}) = \hat{V}(\hat{C}) + \hat{V}(\hat{H}) - \hat{Cov}(\hat{C}, \hat{H})$$

where

$$\tilde{Cov}(\hat{C}, \hat{H}) = \tilde{Corr}(\hat{C}, \hat{H})\, SE(\hat{C})\, SE(\hat{H}),$$

and

$\tilde{Corr}(\hat{C}, \hat{H})$ is an imputed value, equal to the mean correlation over all datasets for which it had been directly estimated from bootstrap estimates as follows:

$$\hat{Corr}(\hat{C}, \hat{H}) = \frac{\hat{Cov}(\hat{C}, \hat{H})}{SE(\hat{C})\, SE(\hat{H})}$$

where

$$\hat{Cov}(\hat{C}, \hat{H}) = \frac{1}{2}\left[\hat{V}(\hat{C}) + \hat{V}(\hat{H}) - \hat{V}(\hat{R})\right].$$

Appendix 2.–Examples of the effects of repeated recapture of halibut on the discard mortality rate.

Four scenarios are shown; two in which the mortality rate is independent of the previous capture event and two where the mortality rate doubles each event. When the 5% mortality rate is independent of previous events (left side examples), the 5% rate correctly predicts the number of dead fish when multiplied by the number of releases. This is true regardless of the number of subsequent release events, because some individual fish are counted more than once as releases. When the mortality rate doubles with each successive event, a mortality rate of 5.27% would have to be multiplied by the number of released fish to correctly predict the number of dead discards.

5% of Fish Recaptured Once

	Mortality rate same each event				**Mortality rate doubles each subsequent event**			
	Event	No. Fish	Mort. Rate	No. dead fish	Event	No fish	Mort. Rate	No. dead fish
	1	10,000	0.05	500	1	10,000	0.05	500
	2	500	0.05	25	2	500	0.10	50
	Total	10,500		**525**	Total	10,500		**550**
	Reported no. releases:			10,500	Reported no. releases:			10,500
	Mortality rate that correctly predicts discard mortality =			**0.0500**	**Mortality rate that correctly predicts discard mortality =**			**0.0524**
	True mortality rate =			0.0525	True mortality rate =			0.0550

5% of Fish Recaptured Twice

	Event	No fish	Mort. Rate	No. dead fish	Event	No fish	Mort. Rate	No. dead fish
	1	10,000	0.05	500	1	10,000	0.05	500
	2	500	0.05	25	2	500	0.10	50
	3	25	0.05	1.25	3	25	0.20	5
	Total	10,525		**526.25**	Total	10,525		**555**
	Reported no. releases:			10,525	Reported no. releases:			10,525
	Mortality rate that correctly predicts discard mortality =			**0.0500**	**Mortality rate that correctly predicts discard mortality =**			**0.0527**
	True mortality rate =			0.0526	True mortality rate =			0.0555