Considerations Concerning Bycatch Control and Abundance-based Prohibited Species Catch Limits for Pacific Halibut in the Bering Sea/Aleutian Islands

Bruce M. Leaman, Ian J. Stewart, and Steven J.D. Martell

Introduction

The North Pacific Fishery Management Council (NPFMC) has initiated an analysis to reduce the Prohibited Species Catch (PSC) limits for Pacific halibut (*Hippoglossus stenolepis*) for the Bering Sea/Aleutian Islands (BSAI) fisheries. PSC of halibut occurs through incidental capture (bycatch) and mortality in non-directed fisheries for groundfish, primarily shallow water flatfishes in the eastern Bering Sea. At its June 2014 meeting the Council identified several options for its future actions and requested information on specific issues associated with the analysis. Previously, we have identified impacts of bycatch mortality in the BSAI on the halibut resource and its fisheries (Hare and Williams 2013, Stewart et al. 2015). One issue upon which the International Pacific Halibut Commission (IPHC) has been asked to comment concerns scaling the PSC limits to the abundance of halibut. Specifically, the Council requested consideration of:

> <u>Biomass-based PSC limits:</u> *The range of potential approaches to establishing a halibut PSC limit based on projections of total biomass, projected spawning biomass, or other appropriate indices of abundance and productivity.*

This document addresses this information request and reviews:

- the current scenarios for bycatch control;
- the process for bycatch reduction;
- the necessary data, as well as the advantages and challenges of abundance-based PSC limits;
- major sources of uncertainty; and
- the potential for evaluating the impacts of using abundance-based limits.

Current scenarios for bycatch control

All directed fisheries have some level of incidental mortality for species that are not the targets of the fishing activity. The major mortality of halibut in non-directed fisheries occurs in on-bottom trawl fisheries for groundfish, throughout the range of halibut occurrence. In theory, the Halibut Convention between the United States and Canada provides the IPHC with the authority to regulate the retention of halibut in fisheries that capture halibut incidentally (McCaughran and Hoag 1992). However, this authority is not unfettered and is subject to the acceptance of any recommended regulatory measures by the contracting parties. Following extensions of fisheries jurisdiction in the U.S. and Canada in 1977, the contracting parties retained authority for allocation of halibut removals among domestic harvesters, but left the IPHC with the authority to make decisions involving the conservation and management of, and the international allocation of harvest from, the halibut stock. This arrangement confers the

IPHC with the primary authority to determine directed removals and the contracting parties with the authority to regulate bycatch mortality. Importantly, in the construction of this regulatory framework, the contracting parties to the Convention noted the need for close coordination between the Commission and the domestic agencies to ensure conservation of the halibut resource.

Conservation measures for the halibut stock have not been implemented consistently among the sectors contributing to removals from the stock. As noted in Stewart and Martell (2015), directed fishing removals and wastage mortality from the halibut stock, which are under the control of the IPHC, have decreased by approximately 53% from 2010-2014. In contrast, coastwide bycatch mortality, not under control of the IPHC, has declined by only 10% over the same period. In addition, the current control measures for bycatch mortality in groundfish trawl fisheries differ greatly among IPHC regulatory areas and between the two countries. Here, we briefly review these measures.

Area 2A (Washington, Oregon, and California)

In Area 2A (Washington, Oregon, and California), the Pacific Fishery Management Council enacted a program of Individual Bycatch Quotas (IBQs) for trawl fisheries beginning in 2011, as part of a comprehensive rationalization of the trawl fisheries. The IBQs, in conjunction with non-retention, mandatory full observer coverage, and incentives for bycatch reduction via groundfish target species quota access have proven to be very effective at reducing trawl fishery bycatch mortality (Jannot et al. 2014). Total halibut bycatch mortality in Area 2A trawl fisheries decreased from approximately 0.399 Mlb (net wt[1]) in 2010 to approximately 0.071 Mlb (-82%) in 2014. Groundfish utilization in the trawl fishery has not returned to pre-rationalisation levels but this is not due exclusively to bycatch controls on halibut. Restrictions on other groundfish species act as significant constraints on total harvests, and groundfish harvesters used only about 25% of their halibut IBQs in 2014.

Area 2B (British Columbia)

Similarly, bycatch mortality control in Area 2B bottom trawl fisheries is currently effected through IBQs, with full observer coverage and non-retention provisions. The IBQs in Area 2B are transferrable among vessels participating in the fishery. The IBQ program in this area was implemented in 1996 and resulted in an immediate reduction of bycatch mortality from approximately 1.52 Mlb in 1995 to 0.3 Mlb (-80%) in 1996, during which no vessel caught more than 50% of its IBQ. Since 1996, the level of bycatch mortality in Area 2B has ranged from 0.143 – 0.346 Mlb annually (Williams 2015a).

It is also significant that in Area 2B, groundfish harvesters have been able to adjust their fishing activities to achieve almost full utilization of available groundfish harvest, while implementing these substantial reductions in halibut bycatch mortality.

Areas 2C, 3, and 4 (Alaska)

In Alaskan fisheries, control of halibut bycatch mortality is currently effected through the use of PSC limits on groundfish fisheries. PSC restrictions on groundfish trawl fisheries were introduced in 1985, following several years of other control measures. A history of PSC implementation is included in Karim et al. (2012) and is presented in Table 1 of Williams

[1] Throughout this report, weights are reported as head-off, eviscerated or net weight. Where metric tons, round weight are reported (e.g. PSC limits), the equivalent net weight will be provided.

(2015b). A summary of current bycatch limits in Alaskan waters, by fishery, is presented in Williams (2015b). As described in that document, the NPFMC adopts halibut bycatch mortality limits for the Alaskan groundfish fisheries during its annual specification process in the fall of each year. Currently, the limits are set by NMFS management area. These limits are fixed in regulation[2] and can only be changed through a formal amendment. For both the GOA and BSAI regions, regulations allow the Council to apportion the trawl and fixed gear limits into seasonal amounts and by fishery, to enable the groundfish fisheries to maximize their groundfish catch within the specified limits. There are two broad levels of PSC application, one for vessel cooperatives and one for the remaining complement of vessels, each applied in trawl and fixed-gear sectors and each with additional levels of complexity within these broad levels.

The 2014 trawl fishery limit in the GOA was 1,848 mt round weight (3.06 Mlb net wt). The trawl limit was divided by season for shallow water and deep water fisheries, as has been the practice since 1991. The 2014 trawl fishery bycatch mortality limit for the BSAI was 3,675 mt (6.0 Mlb). By regulation, a fixed amount of 326 mt (0.5 Mlb) is reallocated to CDQ fisheries (gear nonspecific), leaving 3,350 mt (5.5 Mlb) for all remaining trawl fisheries. However, only 3,200 t (5.3 Mlb) was allocated among fisheries (Williams 2015b).

Incentives to achieve particular bycatch goals in Alaska are socialized across multiple vessels within fishery cooperatives and applied fleet-wide for fishing by non-cooperatives. The control measures for halibut bycatch in Alaskan waters therefore fall somewhere between the IBQ-based programs in Areas 2A and 2B and fishery-wide PSC limits. The primary fishery cooperatives within which halibut PSC is significant (Amendment 80 cooperatives) began in 2008 and a summary of their performance relative to halibut bycatch is presented in Northern Economics (2014). In general, the cooperatives have been below their PSC limits although the mortality occurring in individual target species fisheries has been more variable. The total halibut mortality from all sectors in BSAI has been relatively constant since 2008 but has declined by approximately 14% since 2000 (Williams 2015a).

Process for bycatch mortality reduction

The foregoing section report reviewed the current bycatch control measures used in IPHC regulatory areas and their performance in reducing bycatch mortality. A significant feature of these measures is the hierarchy of effectiveness, with progressively more effective reduction occurring as measures move from fleet-wide, to cooperatives, to individual responsibility frameworks. Major reductions in bycatch mortality have been achieved in Areas 2A and 2B. Both of these areas have implemented mortality management through IBQs, together with rationalized groundfish fisheries and mandatory 100% monitoring. This framework has been developed through principle-based negotiations among the sectors involved in these fisheries, under the auspices of the management agencies. In both areas, the management agency outlined the requirements of monitoring and the necessary results of the programs, leaving the industry advisory committees to develop the working details of the programs.

[2] Prior to 2014, the bycatch limits in the GOA were frameworked, allowing annual changes. In 2013, the NPFMC decided to change that process by putting the limits in regulation, similar to the BSAI bycatch limits. 2014 was the first year of the new process.

In Area 2A, the Pacific Fishery Management Council (PFMC) initiated planning for rationalization of the trawl fishery in 2003, with final implementation in 2011. A detailed background of the process can be viewed here:

http://www.pcouncil.org/groundfish/fishery-management-plan/fmp-amendment-20/#TRARCHIVES

In Area 2B, the rationalization of the trawl fishery, including halibut bycatch management, began with the implementation of IBQs in 1995. The groundfish fishery in Area 2B has subsequently been subject to a management program that is extensively integrated across harvesting sectors and species groups. This program was developed by a broadly-based industry advisory committee beginning in 2003 and implemented as a pilot program from 2006-2009. The integrated management program was made permanent in 2010. A review of this innovative and progressive program is presented in DFO (2009) and is available here:

http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/Groundfish/documents/Groundfish_evaluation.pdf

In both Area 2A and 2B, the provision of regulatory environments incorporating individual responsibility for bycatch as a component of management programs, in conjunction with rationalised trawl fisheries and comprehensive monitoring, has resulted in a major reductions in bycatch and conflicts between directed halibut harvesters and those encountering halibut bycatch in non-directed fisheries. The significance of this cannot be overstated in the context of the reductions in halibut bycatch mortality for the BSAI being considered by the NPFMC. The salient point here is not that IBQs are universal solutions to the conflicts over halibut bycatch mortality, rather it is that this approach to reducing mortality accomplishes both halibut stock management and fishery interaction objectives, while allowing significant groundfish harvest.

Directed halibut harvesters in the BSAI seek reductions in bycatch in order to achieve greater directed fishing yields. ***In our view, reducing bycatch should be the primary goal being pursued, using both available regulatory mechanisms and those used elsewhere but not currently used in the BSAI, prior to consideration of abundance-based PSC limits. That goal is consistent with the stated goals of reducing bycatch 'to the extent practicable' and minimizing the mortality of bycatch, which are embedded in the MSFCMA (the Magnuson Act) National Standard 9. The term 'practicable' should encompass the use of both available regulatory approaches that have been implemented elsewhere in the U.S., and new approaches (e.g., deck sorting).***

While the regulatory incentives used in other venues have not been implemented in the BSAI, and thus bycatch mortality has not been reduced to the lowest levels practicable, we proceed with an examination of abundance-based PSC limits, in response to the Council's information request.

Indices for consideration as scaling factors on PSC limits

If we wish to derive an appropriate process to scale PSC limits with some measure of halibut abundance, we should consider both indices of halibut abundance and the interaction of halibut bycatch rates with the abundance of target groundfish species. Specifically, candidate indices of use may consider:

- the abundance of halibut subject to bycatch mortality;
- the selectivity of halibut by fishing gear in non-target bycatch fisheries;

- the encounter rate of halibut in relation to non-target species abundance;
- the abundance of the total halibut biomass;
- the exploitation status or health of the halibut stock; and
- the availability of data upon which to base indices

Due to the press of time on other Commission activities, we do not examine all of these indices in detail but do provide some commentary on them and indicate where future work may be required or informative.

Metrics of halibut abundance

Adult stock abundance

The only available estimate of halibut adult abundance (numbers and biomass) comes from the annual IPHC stock assessment (e.g., Stewart and Martell 2015). This assessment estimates historical and current coastwide abundance, with projections into the upcoming year. In conjunction with the coastwide estimates of abundance, the annual IPHC setline survey provides information on the distribution and area-specific trends in the adult stock (Webster and Stewart 2015), through a process known as apportionment. Figure 1 shows the trends in apportioned exploitable biomass[3] estimates by subarea within IPHC Area 4, over the past 15 years. Biomass of halibut in Area 4 is down substantially since the historically high levels of the late 1990s and early 2000s. Area 4CDE has been improving modestly over the past three years, while the trend in other areas is essentially flat. These trends are largely borne out by commercial fishery and IPHC WPUE (lbs/skate) survey indices (Figs. 2-3). The absolute scale of these biomass estimates may be sensitive to assessment methods, but the trends are based solely on data.

Juvenile stock abundance

A significant issue in consideration of abundance-based PSC limits in the BSAI is a metric to index the primary size groups of halibut that are subject to bycatch by non-target fisheries. For most of the geographic range of halibut, there are no indices of juvenile halibut abundance available on an annual basis. The sole annual index of abundance for smaller halibut (U26) is the NMFS Eastern Bering Sea (EBS) trawl survey. This survey produces swept-area estimates of halibut abundance. It is an extensive survey sampling the majority of habitat occupied by small halibut and has a time series extending back to 1982 (Fig. 4). The survey trawl is selective for smaller halibut and comparison with setline survey data indicates much lower selectivity for larger halibut (Webster 2014). Indeed, few halibut > 100 cm are encountered on this survey (Fig. 5; Sadorus et al. 2015). For other areas of the Bering Sea, surveys that encounter juvenile halibut are conducted on a triennial or biennial basis. While the lack of annual survey data on juvenile halibut abundance in areas other than the EBS is an impediment to annual indexing, the majority of the halibut bycatch mortality occurs in on-bottom trawl fisheries in the EBS (averaging over 65% from 2000-2014 and increasing over the past three years), where the annual NMFS survey occurs.

The EBS survey indexes halibut abundance in both numbers of fish and biomass. The two metrics of abundance are generally correlated over time (r = 0.593 for 1982-2014) but exhibit

[3] Exploitable biomass represents the portion of the total biomass included in the current harvest policy calculations. It is based on a selectivity schedule that was used in simulating the performance of the harvest control rule and target harvest rate.

some striking differences, particularly beginning in 1992 and 2006. Figure 5 provides some indication of the cause of these differences, illustrating that the abundance by number responds strongly to the presence of the smallest size class of halibut (0-39 cm), especially notable in 2006. The observed biomass of halibut responds later and reflects the growth of fish and progression through the size classes. Since 2006, the abundance of the smallest size class of halibut has decreased dramatically (Fig. 5) while the decrease in the estimated survey biomass occurred later and more gradually. The net result is less correlation ($r < 0.5$) between numbers and biomass of juvenile halibut since 2000.

Correlations of bycatch with metrics of halibut abundance

While existing PSC limits have been largely static, they have not been fully subscribed in recent years. It is nonetheless instructive to examine how bycatch mortality and halibut abundance have been related. Using the indices above, we examined their correlation with the magnitude of halibut bycatch for the BSAI and the EBS (IPHC Area 4CDE, including the Closed Area).

Figure 6 illustrates the relationship of apportioned exploitable biomass estimates and bycatch mortality for the BSAI region, by IPHC regulatory area. The highest correlation of bycatch and biomass by area is for Area 4CDE (r = 0.58), with lower correlations for Area 4A (r = 0.43) and 4B (r = 0.48). Aggregated across all areas (Fig. 7), the correlation rises (r = 0.68). Figure 7 also illustrates that while bycatch mortality and exploitable biomass are correlated, the magnitude of bycatch mortality has not scaled proportionately with halibut biomass for the BSAI region. This lack of direct scaling was also noted by Stewart and Martell (2015).

For Area 4CDE, the area with the highest bycatch mortality, there has been a much more pronounced disparity between the rate of decline in biomass and that of bycatch mortality (Fig. 8). Particularly in the last three years, the catch in the directed halibut fishery has declined sharply while bycatch has increased (Fig. 8). Area 4CDE directed fishery catch limits have often been set at levels above the IPHC harvest policy since 2004, while those for Areas 4A and 4B have generally adhered to the harvest policy. The correlation between halibut bycatch mortality and indices of juvenile abundance from the NMFS EBS trawl survey has been negative for both numbers and biomass of juveniles (Fig. 9). The strength of this inverse correlation has been variable by time period. For the 1990-2014 period, bycatch mortality was inversely correlated with both NMFS survey estimates of juvenile halibut biomass (r = -0.62) and more weakly for numbers (r = -0.49). In the more recent period of 2000-2014 (Fig. 10), these correlations continued to be negative, again more strongly so for halibut biomass (r = -0.72) than for halibut numbers (r = -0.25). Of greatest concern for the applicability of scaling bycatch mortality to halibut abundance are the divergent trends of halibut abundance on the NMFS surveys and the magnitude of bycatch over the past four years. Both numbers and biomass of halibut are decreasing in the EBS while halibut bycatch is increasing (Fig. 10). This is also a period when there have been no closures of the primary trawl fisheries generating bycatch due to halibut PSC limits (Northern Economics 2014).

In summary, correlations of bycatch mortality and metrics of halibut abundance do not indicate that bycatch mortality is strongly dependent on halibut abundance. In recent years, the estimated bycatch levels in groundfish fisheries have been below PSC limits and trends in bycatch mortality are in strongly opposite directions among IPHC regulatory areas in the BSAI.

Influence of groundfish catch levels on halibut bycatch mortality

The limited relationship of halibut bycatch mortality to metrics of halibut abundance raises the obvious question of whether halibut bycatch levels in the groundfish fisheries are more strongly related to groundfish abundance, or at least groundfish catch levels. Beyond the obvious conclusion that a linkage has to exist, interpretation of the available data is complicated by the interaction of observed levels of bycatch with historical measures taken by the groundfish fleet to decrease bycatch and avoid closure of groundfish fisheries. Figures 11 and 12 illustrate the historical trends in catch of the major groundfish fisheries creating bycatch mortality (Pacific cod and flatfishes) and halibut bycatch mortality in the BSAI as whole (Fig. 11) and for the IPHC Area 4CDE (Fig. 12). Flatfish catches have been increasing relatively steadily since 2001 and are inversely correlated (r = -0.81) with BSAI bycatch mortality over the 2000-2013 period (Fig. 11). Similarly, Pacific cod catches have also had weak but inverse relationship (r = -0.36) with bycatch mortality for most of this period. This is also the case for Area 4CDE bycatch over the 2000-2013 period as a whole (r = -0.78 and -0.33, for flatfish and Pacific cod catches, respectively). However, the recent (since 2011) increases in bycatch mortality in Area 4CDE are very strongly and positively correlated with both Pacific cod and flatfish landings (r values of 0.87 and 0.99, respectively). Since both fisheries are increasing over this period, any effect of one fishery is confounded with the other. Bycatch mortality in the BSAI as a whole decreased in 2013, when Pacific cod landings also decreased, while bycatch mortality continued to increase in Area 4CDE, in concert with the continued increase in flatfish landings.

Bycatch rates in the groundfish fisheries producing the bycatch are highly variable. For example, Figure 13 illustrates the combined halibut bycatch mortality for the two major flatfish fisheries in the BSAI (yellowfin and rock soles), together with the catches of these species, over the 2007-2014 period. This variability in encounter rates provides both opportunity and challenges to reducing bycatch. Heterogeneity in bycatch rates may allow temporal or spatial optimization of groundfish catch with reduced bycatch. Indeed, the NPFMC should logically consider spatial allocation of bycatch limits in conjunction with the temporal allocation contemplated in the Council's June motion. However, if this heterogeneity is directly related to heterogeneity in groundfish catch rates, optimization may be more difficult.

Summary

Direct scaling of halibut bycatch limits to available metrics of abundance for halibut does not appear to offer a viable framework for setting PSC limits. The relationships of bycatch mortality to direct measures of juvenile or adult abundance are either lacking, or are temporally and spatially inconsistent. The latter is a critical issue and is related to the movement of halibut. If fish were stationary or largely so, our ability to utilize metrics of abundance in one area for other aspects of management in that area would be much higher than it is, due to the movement of halibut, particularly juveniles. Webster (2015) shows that within 3-5 years of tagging, recovered juvenile halibut (15-65 cm) tagged in the Bering Sea have the potential to move almost anywhere in the geographic range of the halibut stock. This movement can extend from the western Aleutian Islands to Oregon waters. The result of this level of movement is that individual regulatory areas are not self-contained from a stock management perspective. In particular, juvenile abundance in one area is not linked to total halibut stock biomass and the effects of bycatch in one area will be realized in other areas. Proportional bycatch management would be better served through some index of halibut stock abundance. In the next section we suggest a framework for such an approach, to address the Council's information request.

Experience in other regulatory areas offers convincing support for the belief that progress on reducing the level of bycatch mortality in groundfish fisheries is highly likely if lower PSC limits and a companion enabling regulatory environment are created. Significant reductions in bycatch mortality would diminish conflicts among the harvesting sectors, as has been demonstrated in these other IPHC areas. Such reductions should be a precursor to any abundance-based PSC limit discussion and may possibly preclude a need for the latter.

While we do not see an effective framework for direct scaling of PSC limits to available indices of halibut abundance, such a scaling has inherent attractions from fishery management and harvester perspectives. Past and current halibut management has assigned all the responsibility for conservation measures necessary to accommodate changing halibut abundance to the directed fishery (e.g., Fig. 8). Bringing all users into the same conservation envelope provides a configuration that is consistent with the national goals of both countries. The mortalities to the halibut stock from all sources could all be considered independently when management decisions are made.

In the following section we illustrate how an alternative to direct abundance-based scaling of PSC limits can be structured. The background for the total mortality accounting component of this treatment is contained in Stewart et al. (2015). We show how total catch accounting tables can be used to both illustrate specific impacts of changes in PSC limits and to identify what changes in PSC limits would be required to achieve directed halibut Fishery Constant Exploitation Yield (FCEY) management goals.

An alternative to direct abundance-based scaling of PSC limits

Commission staff are in the process of developing a new framework for halibut management decisions, based on accounting for total mortality on the halibut stock (Stewart et al. 2015). A major feature of this framework is the incorporation of bycatch mortality of all sizes of halibut into the decision-making process.

The IPHC's current harvest policy delineates between O26 removals, explicitly included in the annual catch limits, and U26 removals, not included in catch limit calculations. The policy distributes the directed FCEY limits for each regulatory area based on apportioned biomass estimates derived from survey catch rates of O32 halibut and application of fixed harvest rates to those estimates. The policy accounts for only O26 halibut removals from the directed and non-target fisheries in the calculation of exploitation rates and yield. Changes in O26 bycatch therefore directly translate into changes to directed fishery yields but changes in U26 mortality are not visited directly on calculations of available yield. Instead, the effects of changes in U26 mortality do not factor into the FCEY until those effects are realized through eventual changes in stock biomass. This approach is quite atypical in the context of similar fisheries in the North Pacific, and around the world. By the mid-1990s, fisheries reference points based on integrating all sources of mortality into estimates of Spawning Potential Ratio (SPR) were in common use in the United States (Mace and Sissenwine 1993). Current catch limit calculations for the NPFMC and the PFMC processes generally include all sources of mortality and all sizes of fish.

The IPHC staff wishes to adopt a similar approach for halibut management, although elements of the associated harvest policy are still in development, including determination of the appropriate harvest rates. The key element in such a policy is to measure and manage the fishing intensity experienced by the stock. It is common practice to consider fishing intensity in terms of fishing mortality: the catch as a fraction of the stock or as an instantaneous rate of mortality (per year/age). In both cases, there must be a clearly defined set of sizes or ages included in the calculations. Where multiple fisheries are present, and where these fisheries access differing size and age components of the stock, it is not possible to characterize a single fishing mortality rate for all fisheries simultaneously. In these cases, a metric that integrates the different fisheries (and therefore the mortality on different sizes of fish) is required.

Spawning Potential Ratio (SPR; Goodyear 1993) is a commonly used metric that summarizes the fishing intensity of all fisheries accessing different parts of the same population. SPR has two components: 1) the equilibrium spawning biomass in the absence of fishing and 2) the equilibrium spawning biomass given some distribution of fishing mortality at size or age. Without fishing, the spawning biomass produced by a fixed number of incoming recruits will be a simple function of individual growth, the maturity schedule, and the rate of natural mortality. Fishing just adds an additional source of mortality at each age. However, some of the fish that would have died of natural causes are caught first, such that natural and fishing mortality are not simply additive annual factors. The ratio of equilibrium spawning biomass with fishing to that without fishing is SPR. SPR calculations are frequently summarized as $F_{XX\%}$, such that the XX% represents the percentage reduction in equilibrium spawning biomass: 100% as fishing mortality approaches zero, to 0% as fishing mortality results in no fish surviving to reach maturity.

This metric integrates fishing intensity across multiple sources, where selectivity may differ and traditional age-range dependent fishing mortality rate (F) or harvest fraction calculations can be misleading. Because the SPR metric includes all sources and sizes of mortality, it can be used to directly compare potential halibut fishery yield associated with different levels of total and U26 bycatch and can therefore be used to define a harvest target for the stock. This conceptual extension to the current harvest policy allows for quantification of the impacts of bycatch on the halibut stock via the yield estimates, rather than in terms of adult equivalents or equilibrium spawning biomass units. SPR is also a logical choice for defining fishing intensity where trade-offs among fisheries and size-limits within fisheries need to be directly evaluated in a common framework.

We suggest that an SPR approach, using harvest targets based on fishing intensity, will provide a comprehensive framework for evaluating and managing the mortality arising from all removals from the halibut stock. SPR can be used to define the level of total fishing intensity that is consistent with the target levels of mortality. This conceptual approach is identical to that used in Hare (2011), in order to include O26 mortality into the target harvest rates. The target fishing intensity equates to a target SPR, which can then be used to set the scale of all removals under differing distributions of those removals among fisheries and sizes of halibut. The apportionment results and relative harvest rate targets by regulatory area still define the distribution of the TCEY. Both the target distribution of the TCEY among regulatory areas and the assumption that the effects of U26 mortality are distributed across the entire stock remain the same.

The feature of SPR-based management that commends it for use in managing bycatch mortality is that it places all removals into the same context. This means that it is fundamentally an abundance-based approach but one which uses an *indirect* index of abundance. Managers can use this approach to explicitly assess the impact of constituent removals on stock management goals. The SPR-target and the relative distribution of TCEY from apportionment and relative target harvest rates by regulatory area can be achieved by solving for the fishery landings (and wastage) given any level of bycatch, or by solving for the bycatch given any level of fishery landings (and wastage). Changes to fishing practices that alter the projections of wastage for a given level of fishery landings can also be included. There are therefore multiple entry points possible for management actions and trade-offs among fisheries can be directly evaluated.

An example of total mortality accounting and management

Here we use data from total removals occurring in 2013 and the IPHC assessment to derive harvest projections[4]. This analysis uses the 2013 stock assessment models (Stewart and Martell 2014), apportionment estimates, and current harvest policy calculations (Webster and Stewart 2014) to investigate how changes in U26 and O26 removals impact the annual TCEY and FCEY values. This is done via direct comparison with the results of the 2013 IPHC process; harvest policy calculations are repeated under different projected levels of BSAI bycatch. For simplicity, this analysis focuses on the trade-offs between CEYs and bycatch. However, changes in any other removal constituent could be included in a similar manner. This presentation uses a subset of results from Stewart et al. (2015) for the BSAI only.

We begin with the results of apportionment and application of current harvest policy which generated the Blue Line FCEY values for 2014 (Table 1). This harvest policy table is first extended to show each of the individual components included in the TCEY, as well as all sizes of mortality by regulatory area (Table 2). Comprised predominantly of bycatch, the 2013 U26 mortality was estimated to be 2.92 Mlb, or 8% of the total 36.41 Mlb removals. In order to illustrate how changes in U26 and O26 mortality influence the TCEY and FCEY, values were recalculated using BSAI bycatch values that were 20% above and below the estimates from 2013. This calculation integrates the changes in the distribution of halibut mortality among commercial, recreational, and subsistence catches, as well as estimates of wastage, associated with differing quantities of directed fishery landings.

Changes in BSAI bycatch of +/- 20% show direct changes in FCEY and total mortality, but the results differ by specific regulatory area and indicate that area 4CDE is the most sensitive because the bulk of the bycatch mortality occurs in this area (Tables 3-4). A 20% increase in bycatch results in the FCEY for 4CDE dropping from 0.64 (at the Blue Line) to 0.2 Mlb, and a decrease of 20% results in an increase in 4CDE to 1.07 (Tables 3-4). In Area 4CDE, for all values of estimated bycatch at least 30% greater than 2013, the FCEY would be 0 for the current harvest policy. Areas 4A and 4B are much less sensitive due to a much lower ratio of bycatch to directed fishery harvest.

To illustrate how SPR-based management using the directed fishery yield (FCEY) as the control point would occur, the same calculations are then repeated but adjusting FCEYs, and then finding the associated level of removals from other sources required to maintain the same SPR target. For example, if the SPR target at the Blue Line generated fishing mortality that reduced the stock to 45% of unfished abundance ($F_{45\%}$), an increase in the FCEY would require changes to other removals to achieve the same $F_{45\%}$ fishing mortality. In this example, changes in bycatch result in changes to directed fishery yields that are greater than just the change in O26 mortality: this is due to the additional effects of the U26 removals. In this case, a 20% reduction in BSAI bycatch results in an FCEY of 25.5 Mlb (Table 6), compared to the Blue Line value of 24.5 (Table 2), while the reduction that did not account for U26 removals resulted in an FCEY of 25.1 (Table 4). These results are consistent with previous analyses finding approximately a 1:1 relationship in total lost yield due to all sizes of bycatch.

[4] These results are not based on the current (2014) stock assessment, and will therefore differ in the exact levels of removals, however the qualitative comparison of effects remains representative.

Under the current harvest policy, there are no changes to annual removals in Areas 2A-3B, despite the change in productivity that would be expected from immigration of some of those U26 fish over their lifetime. Applying the extended accounting for total fishing intensity, changes in BSAI bycatch correspond to changes in the FCEY and TCEY values across all regulatory areas (Tables 5-6). This is due to the distributed effects of U26 mortality. The current assumption is that U26 effects are distributed in proportion to the productivity of the stock as a whole, therefore changes in the TCEY among regulatory areas are most pronounced for areas that have larger apportioned biomass estimates. The largest change occurs in Area 3A, where the FCEY goes from 9.43 Mlb at the Blue Line (and for a 20% reduction in the BSAI bycatch when U26 mortality is not accounted for) to 9.59 when the same SPR is maintained. The clear difference in these calculations is that any response to changes in bycatch in the FCEY, up or down, is of greater magnitude when all sizes of mortality are accounted for. Ongoing research at the IPHC to evaluate size-limits, discard mortality rates in the directed fishery, and the interaction of bycatch with total fishing mortality is yielding very similar results.

The salient points of this example are that when using FCEY as the control variable, the FCEY responds only to the change in O26 removals under the current harvest policy, and the TCEY does not respond to changes in coastwide bycatch, despite potentially large changes in total mortality (Table 7). By extending the accounting to maintain the same level of fishing intensity (SPR), an increase in coastwide bycatch results in a decrease in the FCEY, TCEY and total mortality (Table 7). In the context of abundance-based PSC limits, this example can be used in reverse. If we wish to increase the BSAI FCEY by approximately 0.7 Mlb and maintain the same level of fishing intensity, we would need to decrease the BSAI PSC mortality by approximately 20%, or about 0.7 Mlb.

Summary

The foregoing example outlines how SPR-based management can incorporate mortality from all sources. Further, it provides an indirect index of abundance (SPR and its analogue, the $F_{xx\%}$ depletion metric) which can be tied to any fishery removal control variable. Maintaining the same level of fishing intensity (the $F_{xx\%}$) automatically scales the control variable to the target conservation level for the stock.

Stewart et al. (2015) outline a number of uncertainties and required refinements concerning the implementation of SPR-based total mortality management. Chief among these is the need to undertake the Management Strategy Evaluation of this approach and develop the appropriate harvest policy, including target SPR reference points and control rules, for the approach. A potential ‘bridge’ from the current harvest policy to an SPR-based accounting analog would be to adopt the $F_{XX\%}$ estimated for the Blue Line in the 2014 stock assessment. The 2014 stock assessment estimated a harvest intensity of $F_{46\%}$, similar to targets used for species of comparable life-history characteristics elsewhere. Such a change would not address the adequacy of the current harvest policy for meeting the management objectives of the Pacific halibut fishery, but would provide for a static target for future fishing intensity and the continued development of management of all sizes and sources of halibut mortality pending a fully revised harvest policy.

A second source of considerable uncertainty concerns the distributed impact of U26 mortality in the BSAI on other regulatory areas. Currently, impacts are assumed to occur in proportion to adult biomass distribution and no specific migration hypotheses are invoked.

Known differences in migration probabilities by age and length could have considerable impact on downstream effects of BSAI mortality.

The extended accounting, using SPR in the context of the current harvest policy, provides additional information for the annual process of setting removal limits, whether they are for the directed fishery or other removals such as bycatch. In this context, all removals are scaled within the same framework, providing a link to the Council's request for information on abundance-based PSC limits. It does not define what the 'right' level of bycatch (or any other removal) should be but it does provide the necessary framework for their evaluation. Accounting for halibut removals of all sizes represents a conceptual extension of the current harvest policy, but not a change in the implicit logic of the approach. This analysis does broaden the scope of the policy, providing an analog in total mortality which avoids future changes in realized fishing intensity. Further, it allows for the explicit evaluation of trade-offs between removals of halibut associated with different fisheries and potential changes in the size structure of these removals in response to management actions. All sources of mortality are now 'on the table' for consideration in the same units. This analysis can therefore serve as the basis for direct comparisons within and among regulatory areas of the 'exchange rate' among fisheries in terms of pounds of halibut removals. This approach should serve to elevate the discussion regarding such trade-offs; however, it does not presuppose any changes to current management by the U.S. Councils, DFO, or the IPHC.

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List of Figures

Tables

Table 1. Apportionment and harvest policy table from 2013 based on the Blue Line (current IPHC harvest policy). All biomass values are reported in millions of net pounds (From: Webster and Stewart 2014).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
Exploitable bio.	4.03	26.64	25.44	56.07	23.14	9.69	7.23	18.06	170.29
Percent of total	2.4%	15.6%	14.9%	32.9%	13.6%	5.7%	4.2%	10.6%	100.0%
Harvest rate (%)	21.5%	21.5%	21.5%	21.5%	16.1%	16.1%	16.1%	16.1%	19.7%
Total CEY	0.87	5.73	5.47	12.05	3.73	1.56	1.17	2.91	33.49
Other removals (O26)	0.14	0.74	1.31	2.63	0.90	0.71	0.34	2.27	9.04
Fishery CEY	0.72	4.98	4.16	9.43	2.84	0.85	0.82	0.64	24.45

Table 2. Projected 2014 removals (millions net pounds) with total mortality accounting, based on the Blue Line (current IPHC harvest policy) from 2013.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.01	0.04	0.00	0.51	0.26	0.47	0.13	1.42	2.83
Total U26	0.01	0.04	0.01	0.52	0.30	0.48	0.14	1.42	2.92
O26 Non-FCEY									
Wastage	0.02	0.14	NA	NA	0.24	0.05	0.02	0.02	0.49
Bycatch	0.12	0.19	0.01	0.93	0.62	0.63	0.32	2.23	5.05
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.14	0.74	1.31	2.63	0.90	0.71	0.34	2.27	9.05
O26 FCEY									
Wastage	NA	NA	0.08	0.33	NA	NA	NA	NA	0.41
CSP Sport	0.31	0.61	0.76	1.78	NA	NA	NA	NA	3.47
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.38	4.37	3.32	7.32	2.84	0.85	0.82	0.64	20.54
Total FCEY	0.72	4.98	4.16	9.43	2.84	0.85	0.82	0.64	24.45
TCEY	0.87	5.72	5.47	12.05	3.73	1.56	1.17	2.91	33.49
Total Mortality	0.87	5.77	5.48	12.58	4.04	2.04	1.30	4.33	36.41

Table 3. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% increase in bycatch in Areas 4A, 4B, 4CDE.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.01	0.04	0.00	0.51	0.26	0.57	0.16	1.70	3.24
Total U26	0.01	0.04	0.01	0.52	0.30	0.57	0.16	1.70	3.32
O26 Non-FCEY									
Wastage	0.02	0.14	NA	NA	0.24	0.04	0.02	0.01	0.47
Bycatch	0.12	0.19	0.01	0.93	0.62	0.76	0.38	2.68	5.69
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.14	0.74	1.31	2.63	0.90	0.83	0.41	2.71	9.66
O26 FCEY									
Wastage	NA	NA	0.08	0.33	NA	NA	NA	NA	0.41
CSP Sport	0.31	0.61	0.76	1.78	NA	NA	NA	NA	3.47
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.38	4.37	3.32	7.33	2.84	0.73	0.76	0.20	19.92
Total FCEY	0.72	4.98	4.16	9.43	2.84	0.73	0.76	0.20	23.83
TCEY	0.87	5.72	5.47	12.06	3.73	1.56	1.17	2.91	33.49
Total Mortality	0.87	5.76	5.48	12.59	4.04	2.13	1.33	4.61	36.80

Table 4. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% reduction in bycatch in Areas 4A, 4B, 4CDE.

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.01	0.04	0.00	0.51	0.26	0.38	0.11	1.13	2.43
Total U26	0.01	0.04	0.01	0.52	0.30	0.38	0.11	1.14	2.51
O26 Non-FCEY									
Wastage	0.02	0.14	NA	NA	0.24	0.05	0.02	0.03	0.52
Bycatch	0.12	0.19	0.01	0.93	0.62	0.50	0.26	1.78	4.41
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.14	0.74	1.31	2.63	0.90	0.59	0.28	1.84	8.43
O26 FCEY									
Wastage	NA	NA	0.08	0.33	NA	NA	NA	NA	0.41
CSP Sport	0.31	0.61	0.76	1.78	NA	NA	NA	NA	3.47
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.38	4.37	3.32	7.33	2.84	0.97	0.88	1.07	21.15
Total FCEY	0.72	4.98	4.16	9.43	2.84	0.97	0.88	1.07	25.06
TCEY	0.87	5.72	5.47	12.06	3.73	1.56	1.16	2.91	33.49
Total Mortality	0.87	5.76	5.48	12.59	4.04	1.95	1.27	4.05	36.00

Table 5. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% increase in bycatch in Areas 4A, 4B, 4CDE accounting for U26 mortality by maintaining the same fishing intensity (SPR).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.08
Bycatch	0.01	0.04	0.00	0.51	0.26	0.57	0.16	1.70	3.24
Total U26	0.01	0.04	0.01	0.52	0.30	0.57	0.16	1.70	3.32
O26 Non-FCEY									
Wastage	0.02	0.14	NA	NA	0.24	0.04	0.02	0.00	0.46
Bycatch	0.12	0.19	0.01	0.93	0.62	0.76	0.38	2.68	5.69
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.14	0.74	1.31	2.63	0.89	0.83	0.41	2.71	9.65
O26 FCEY									
Wastage	NA	NA	0.08	0.32	NA	NA	NA	NA	0.40
CSP Sport	0.31	0.60	0.75	1.75	NA	NA	NA	NA	3.41
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.37	4.31	3.26	7.20	2.79	0.71	0.75	0.16	19.55
Total FCEY	0.71	4.92	4.09	9.27	2.79	0.71	0.75	0.16	23.40
TCEY	0.85	5.65	5.40	11.90	3.68	1.54	1.16	2.87	33.05
Total Mortality	0.86	5.69	5.41	12.42	3.98	2.11	1.32	4.57	36.36

Table 6. Projected 2014 removals (millions net pounds) based the Blue Line and a 20% reduction in bycatch in Areas 4A, 4B, 4CDE accounting for U26 mortality by maintaining the same fishing intensity (SPR).

	2A	2B	2C	3A	3B	4A	4B	4CDE	Total
U26									
Wastage	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.09
Bycatch	0.01	0.04	0.00	0.51	0.26	0.38	0.11	1.13	2.43
Total U26	0.01	0.04	0.01	0.53	0.30	0.38	0.11	1.14	2.52
O26 Non-FCEY									
Wastage	0.02	0.15	NA	NA	0.24	0.06	0.02	0.03	0.52
Bycatch	0.12	0.19	0.01	0.93	0.62	0.50	0.26	1.78	4.41
Non-CSP Sport	NA	NA	0.90	1.44	0.02	0.03	0.00	0.00	2.39
Pers./Subs.	NA	0.41	0.40	0.25	0.02	0.01	0.00	0.03	1.11
Total Non-FCEY	0.14	0.74	1.31	2.63	0.90	0.59	0.28	1.84	8.44
O26 FCEY									
Wastage	NA	NA	0.08	0.33	NA	NA	NA	NA	0.41
CSP Sport	0.32	0.62	0.78	1.81	NA	NA	NA	NA	3.53
Pers./Subs.	0.03	NA	NA	NA	NA	NA	NA	NA	0.03
Fishery Landings	0.39	4.44	3.38	7.45	2.88	0.99	0.90	1.11	21.53
Total FCEY	0.73	5.06	4.24	9.59	2.88	0.99	0.90	1.11	25.50
TCEY	0.88	5.80	5.55	12.22	3.78	1.58	1.18	2.95	33.94
Total Mortality	0.88	5.84	5.56	12.74	4.08	1.97	1.29	4.09	36.46

Table 7. Comparison of coastwide projected 2014 removals (millions net pounds) based the Blue Line, alternate levels of bycatch in the BSAI (Areas 4A, 4B, 4CDE), and current vs. extended accounting via SPR. Target TCEY distribution, based on apportionment, is maintained in all projections (Detailed results in Tables 2-6).

Alternative:	Total U26	Total O26 Non-FCEY 2A-3B	Total O26 Non-FCEY BSAI	Total FCEY 2A-3B	Total FCEY BSAI	Total TCEY 2A-3B	Total TCEY BSAI	Total Mortality
Blue Line	2.92	5.72	3.32	22.13	2.31	27.84	5.64	36.41
<u>Current accounting</u>								
BSAI Bycatch (+20%)	3.32	5.72	3.95	22.13	1.69	27.84	5.64	36.80
BSAI Bycatch (-20%)	2.51	5.72	2.71	22.13	2.92	27.84	5.64	36.00
<u>Extended accounting</u>								
BSAI Bycatch (+20%)	3.32	5.71	3.95	21.78	1.62	27.48	5.57	36.36
BSAI Bycatch (-20%)	2.52	5.72	2.71	22.50	3.00	28.23	5.71	36.46

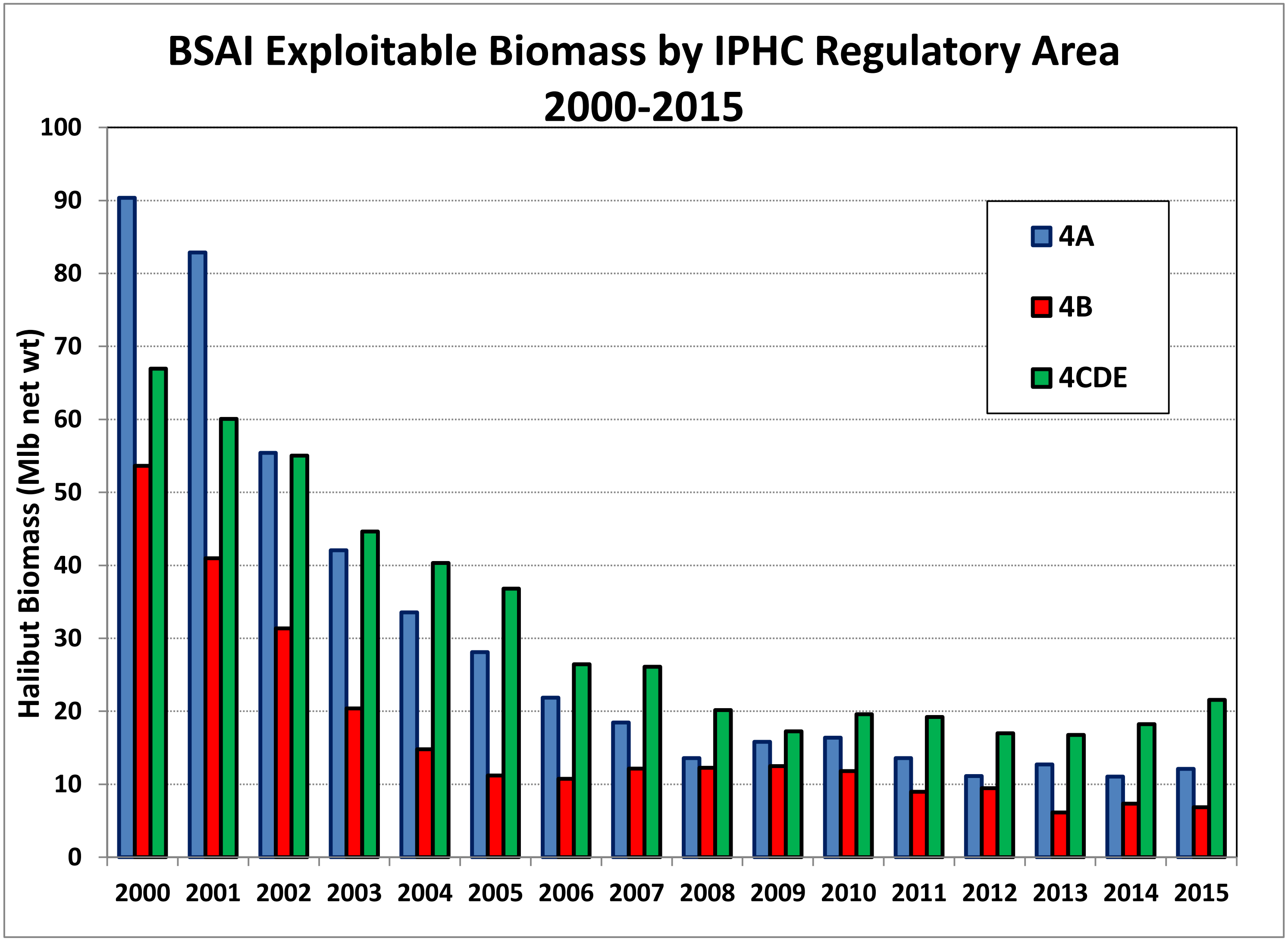

Figure 1. Estimated exploitable biomass of Pacific halibut in the BSAI, by IPHC regulatory area, 2000-2015.

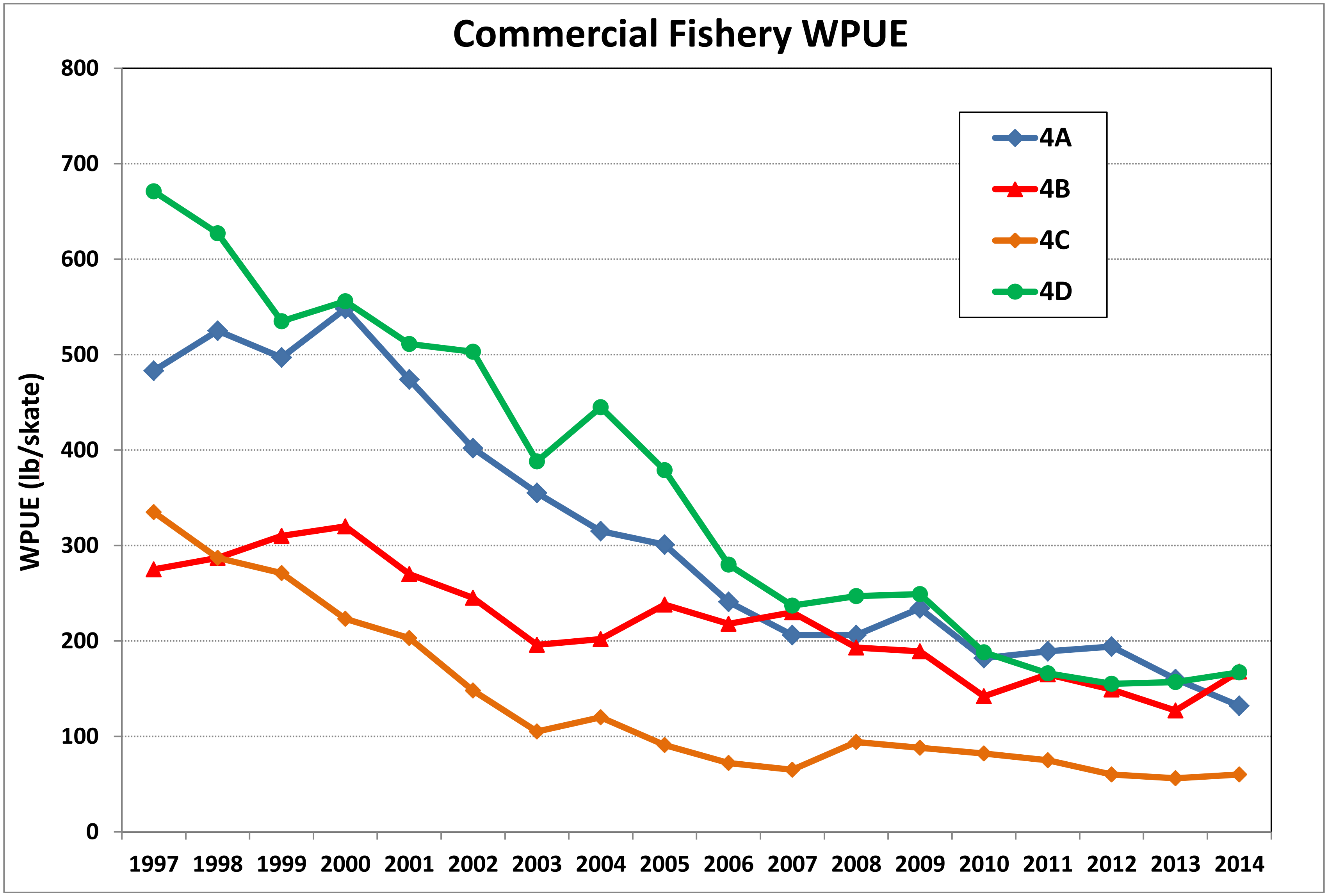

Figure 2. Commercial halibut fishery catch rate (WPUE, lb/skate net wt) by IPHC regulatory area, 1997-2014.

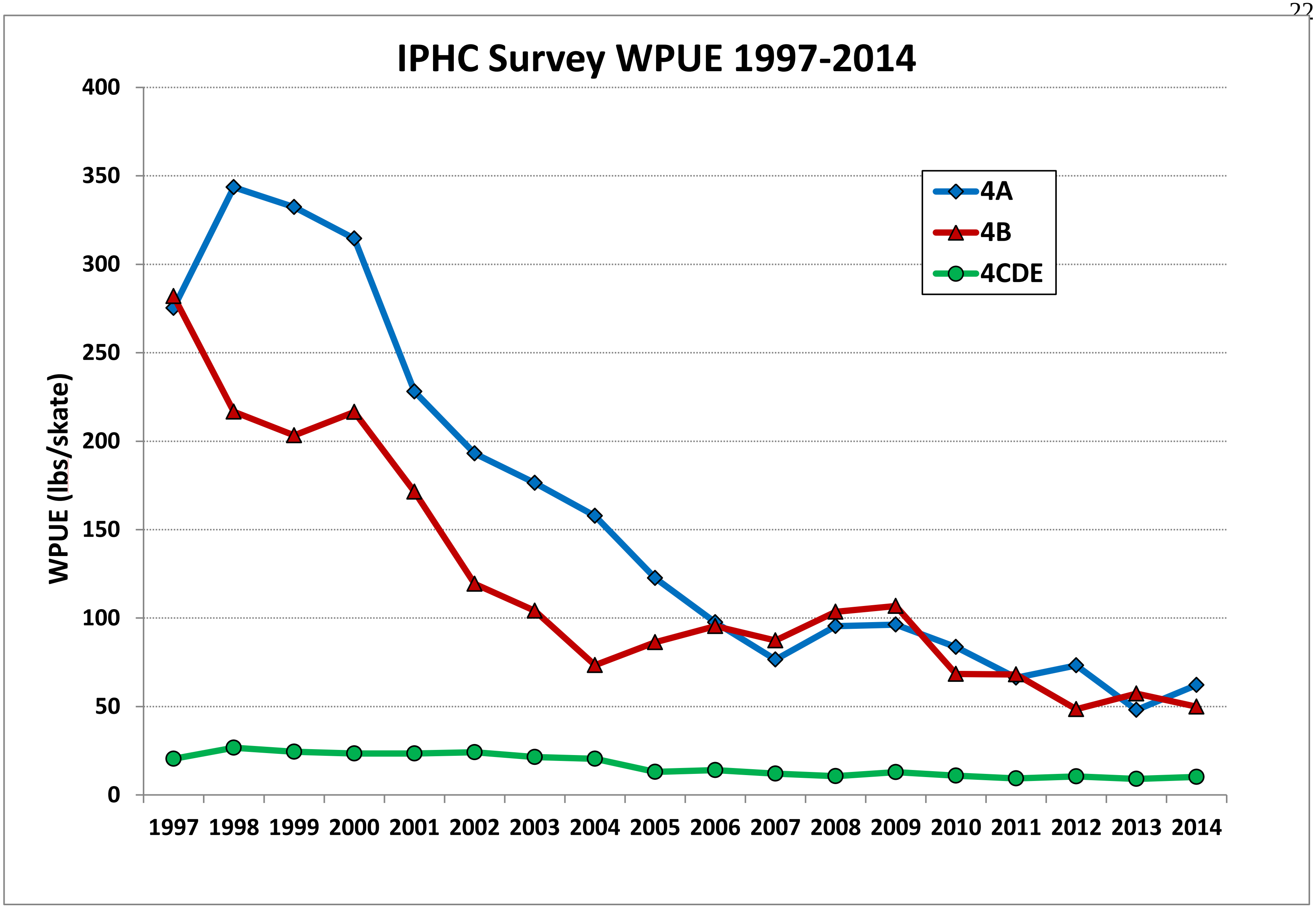

Figure 3. IPHC setline survey catch rate (WPUE, lb/skate net wt) by IPHC regulatory area, 1997-2014.

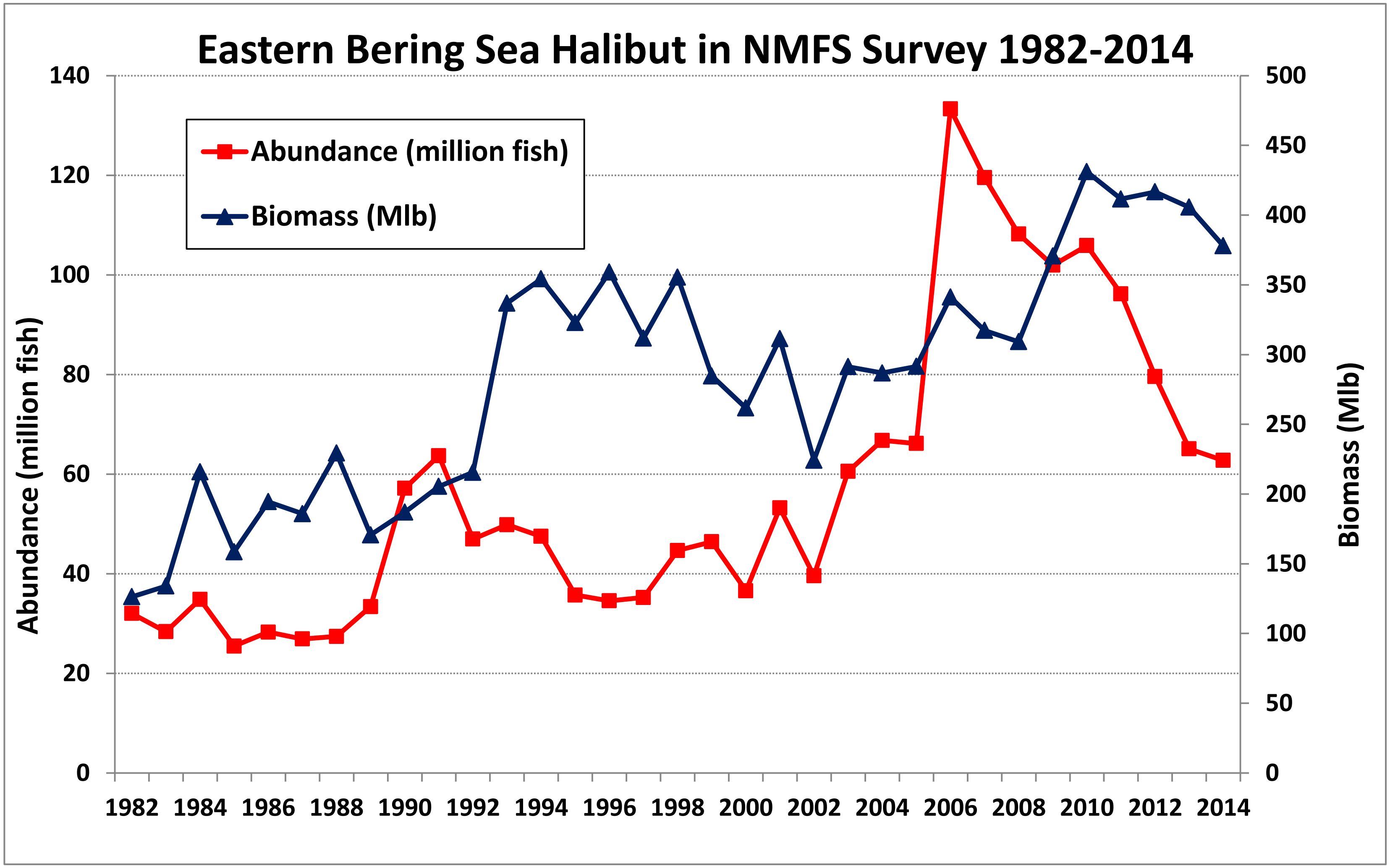

Figure 4. Estimated numbers and biomass of Pacific halibut from the NMFS EBS trawl survey, 1982-2014.

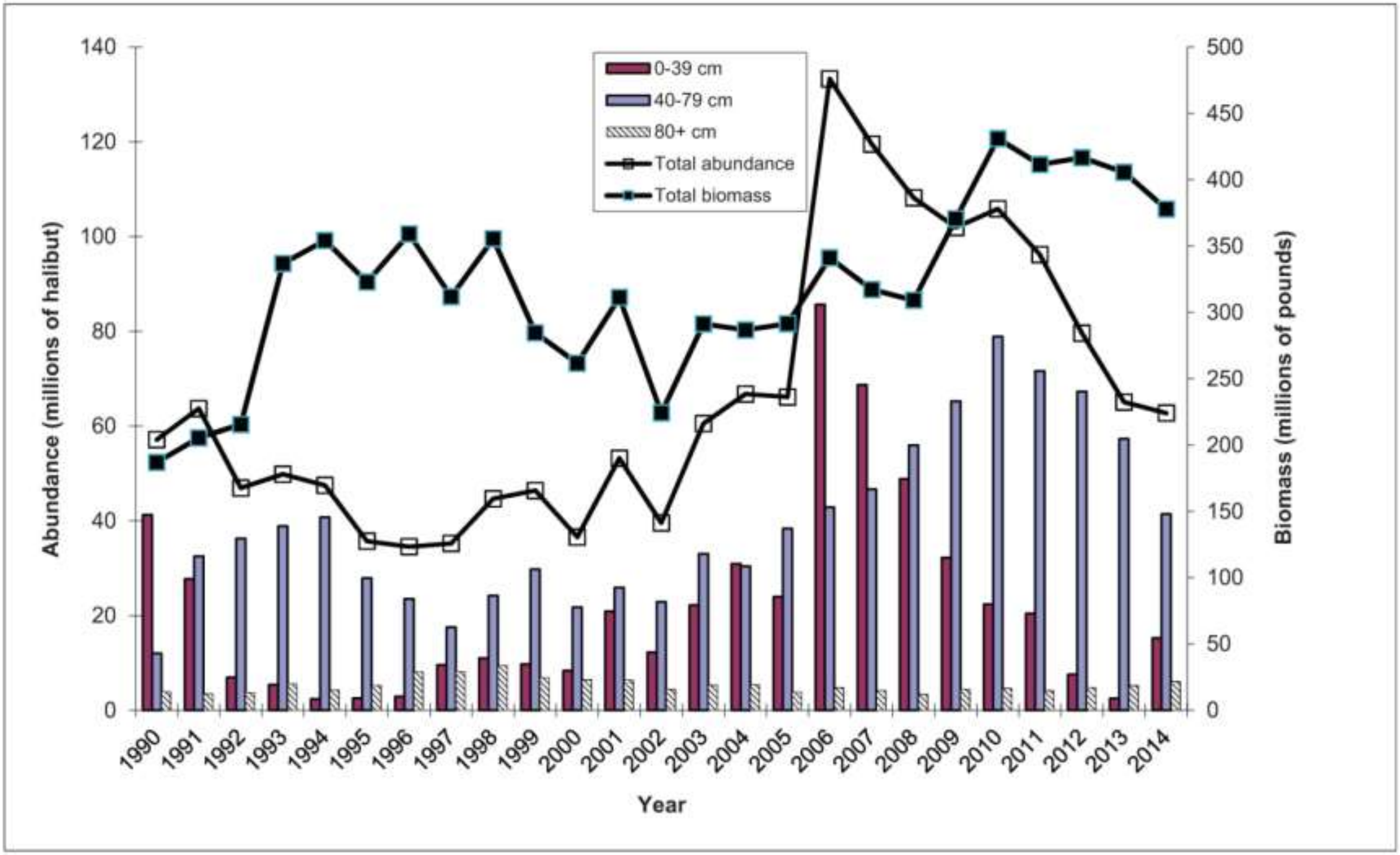

Figure 5. Halibut numbers and biomass, by length class, estimated from the NMFS EBS trawl survey, 1990-2014.

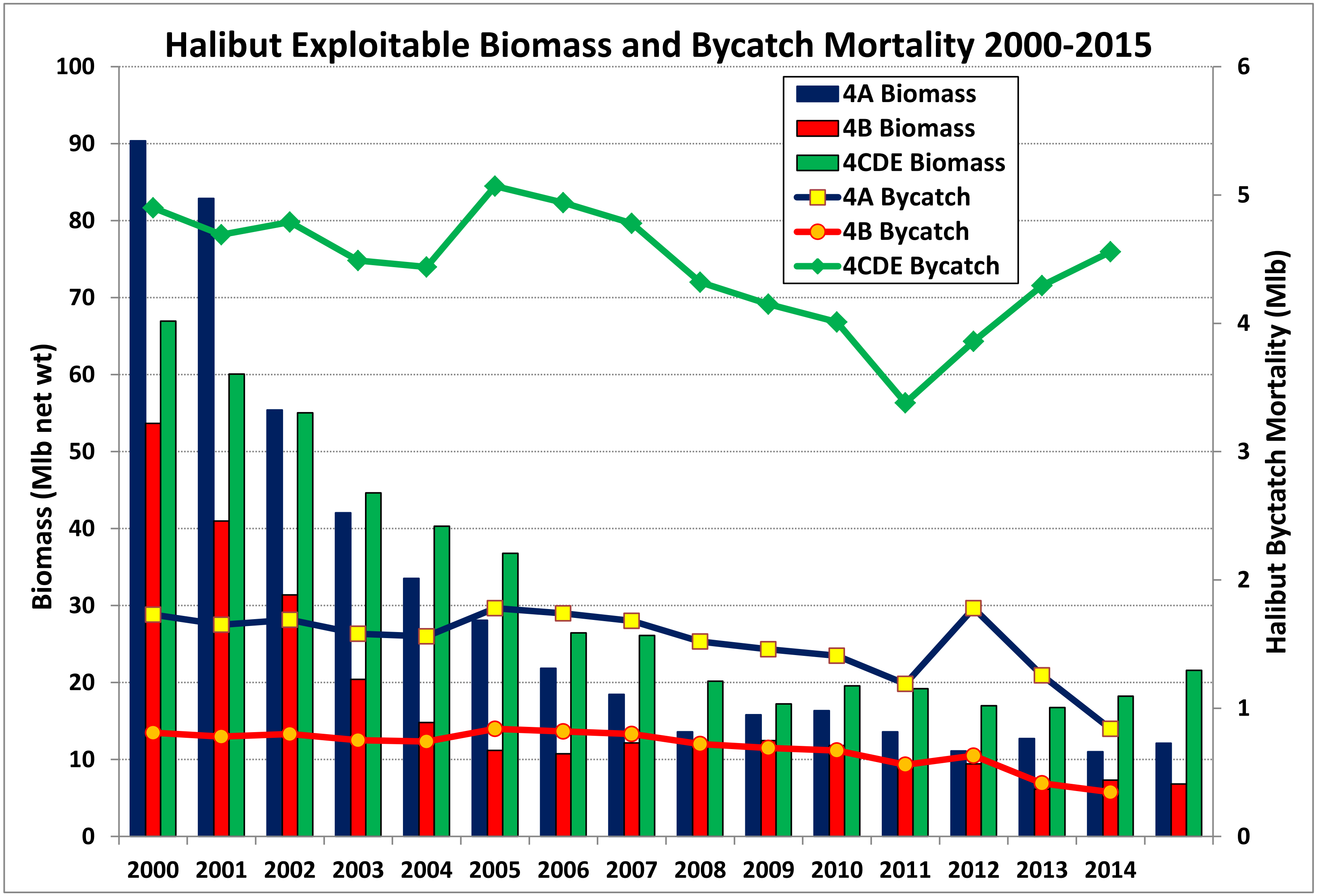

Figure 6. Halibut exploitable biomass and bycatch mortality, by IPHC regulatory area, 2000-2015.

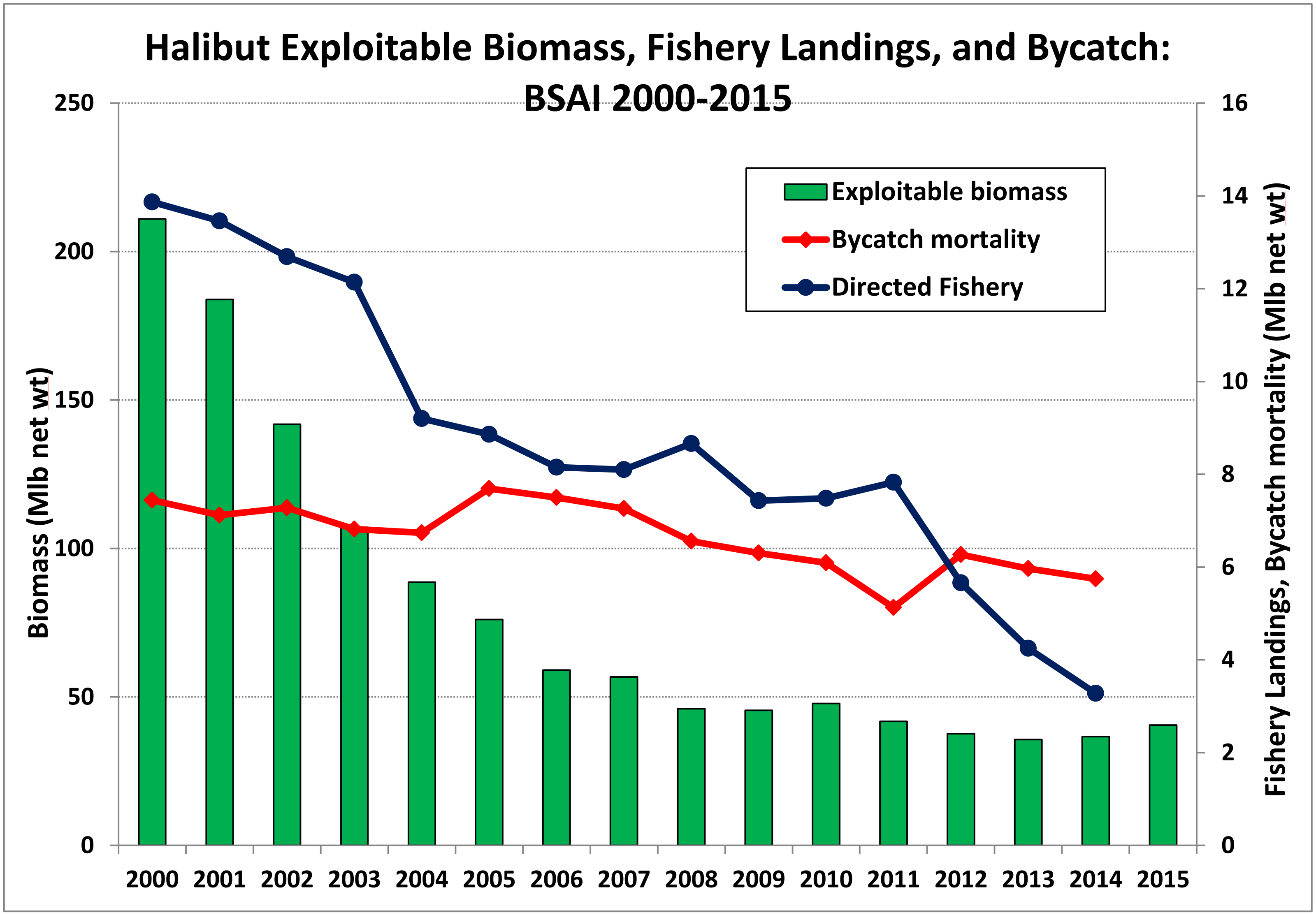

Figure 7. Halibut exploitable biomass, fishery landings, and bycatch mortality for the BSAI region, 2000-2015.

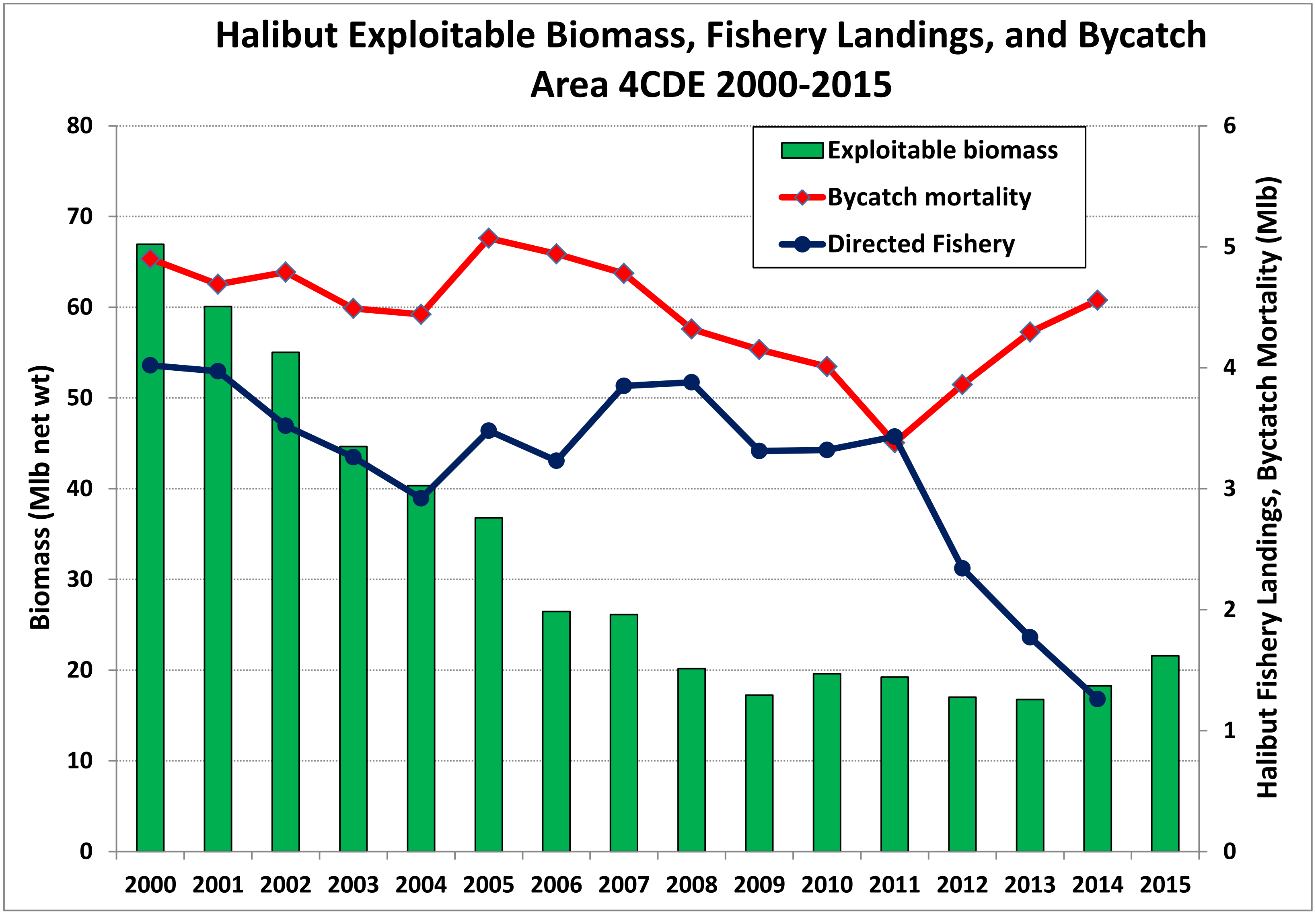

Figure 8. Halibut exploitable biomass, fishery landings, and bycatch mortality for IPHC Area 4CDE (EBS), 2000-2015.

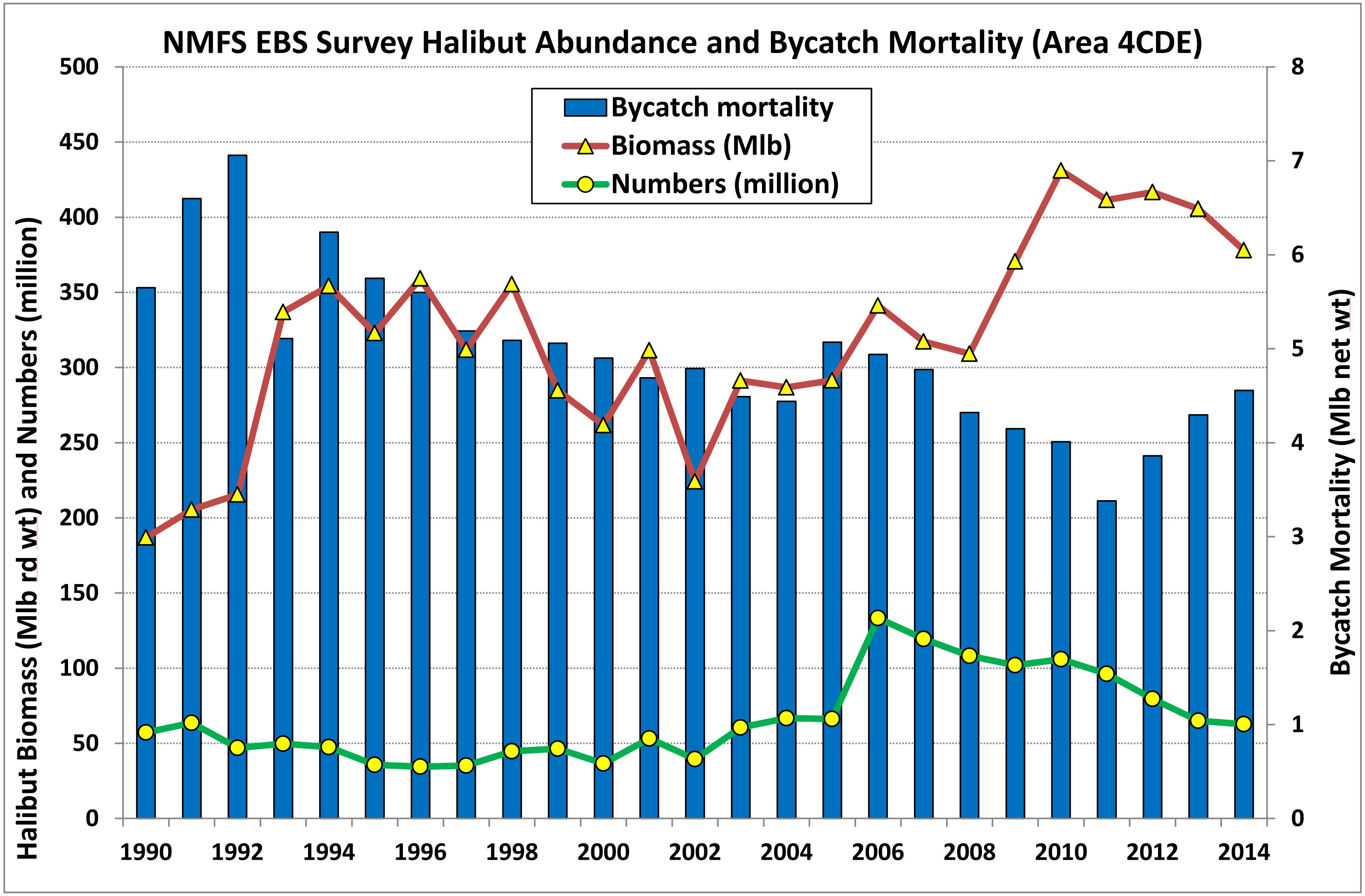

Figure 9. NMFS EBS survey estimates of halibut numbers and biomass, and halibut bycatch mortality for IPHC Area 4CDE, 1990-2014.

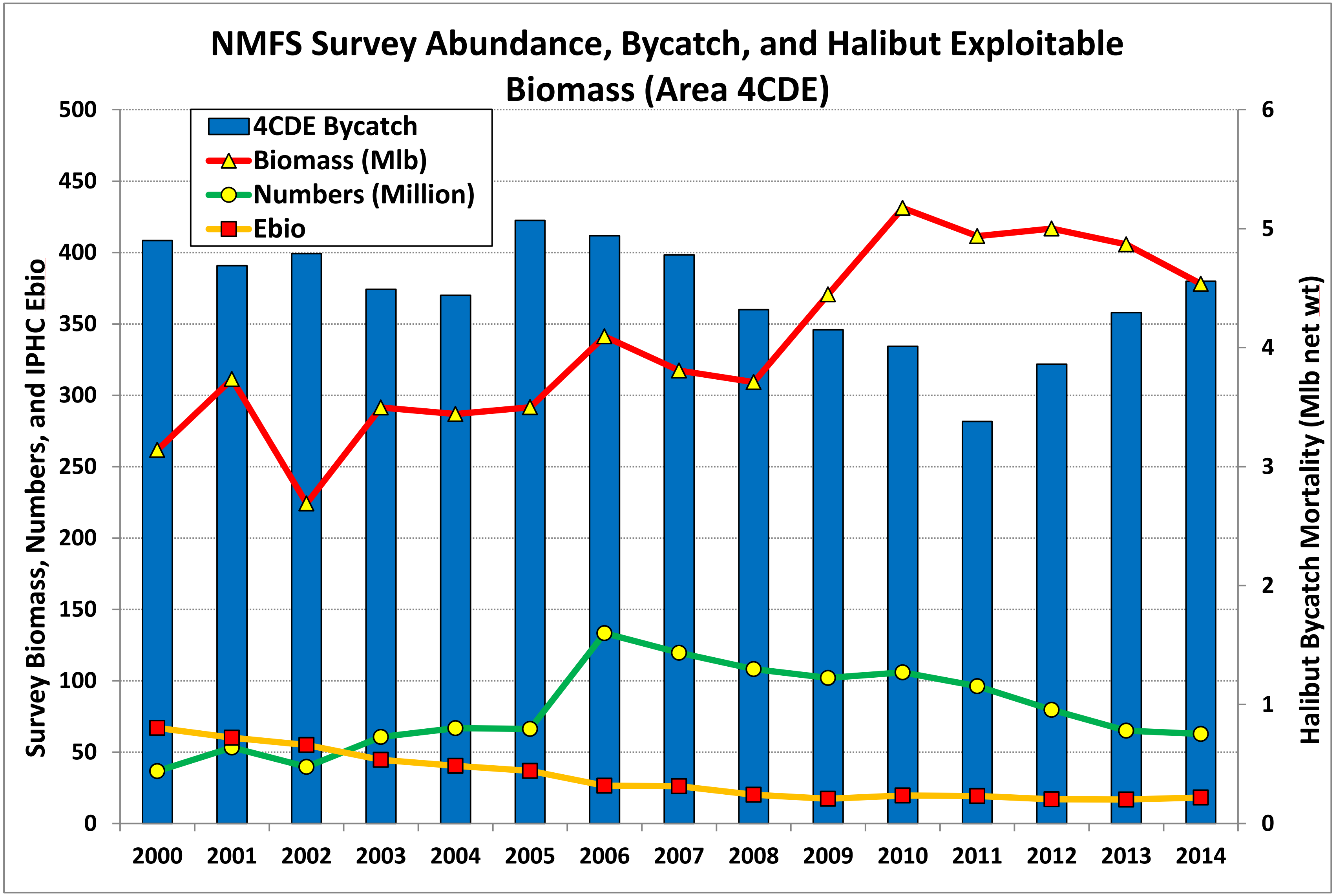

Figure 10. NMFS EBS survey estimates of halibut numbers and biomass, IPHC estimated exploitable biomass, and halibut bycatch mortality for IPHC Area 4CDE, 2000-2014.

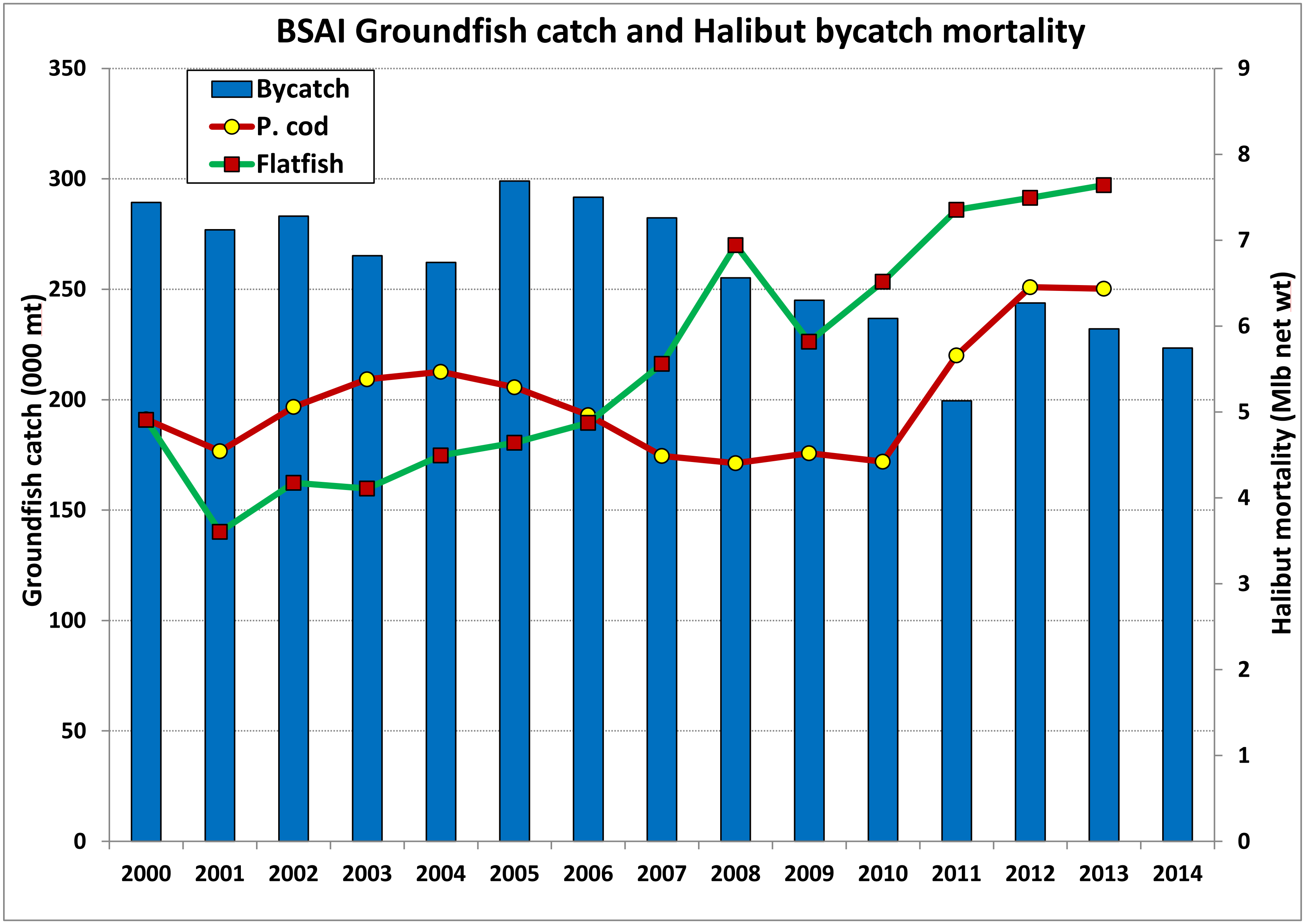

Figure 11. BSAI groundfish catch and halibut bycatch mortality, 2000-2014.

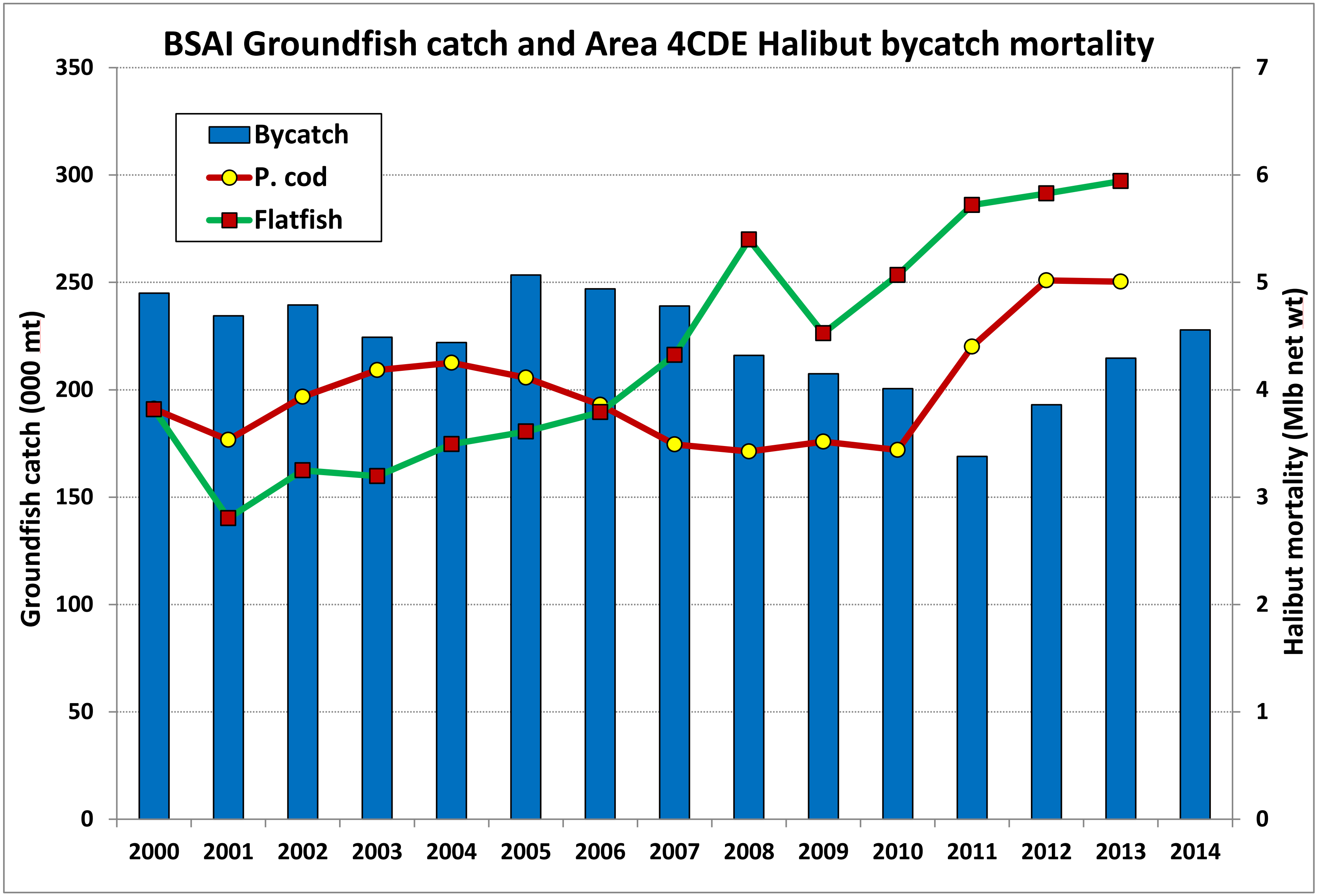

Figure 12. BSAI groundfish catch and Area 4CDE bycatch mortality, 2000-2014.

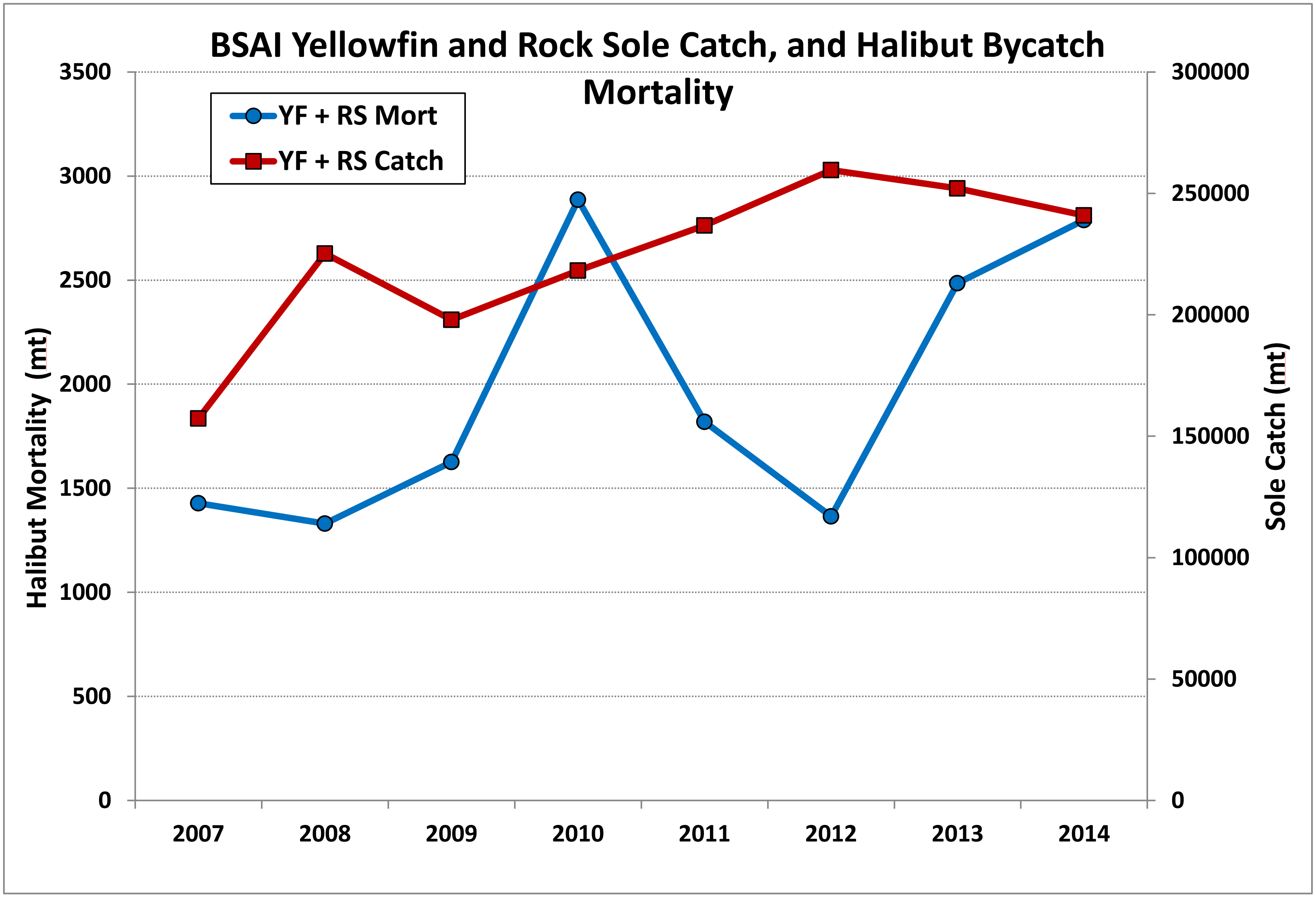

Figure 13. BSAI flatfish catch and bycatch mortality in the yellowfin and rock sole fisheries, 2004-2014.