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Evaluating the efficacy of salmon bycatch measures using fishery-dependent data

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The walleye pollock (*Gadus chalcogrammus*) fishery in the Bering Sea is one of the largest fisheries in the world. The North Pacific Fishery Management Council (NPFMC) provides management advice for this fishery, including the development of measures to minimize salmon bycatch to the extent practicable, one of the stated objectives of the US Magnuson–Stevens Fishery Conservation and Management Act National Standard Guidelines. Salmon have a unique cultural and nutritional importance in the State of Alaska and are the subject of fully allocated mixed commercial, recreational, and subsistence fisheries. Chinook salmon (*Oncorhynchus tshawytscha*) stocks in Alaska have been declining for the last decade, and all sources of mortality are being considered to help in rebuilding stocks. Given the extensive scientific National Marine Fisheries Service observer data collection programme, the NPFMC has developed bycatch management measures that place limits by fishery sector on the allowable catch of Chinook salmon. Part of this programme includes industry-proposed incentive programmes designed to encourage lower bycatch. Evaluating the efficacy of the new measures poses a number of challenges, particularly in light of changing ocean conditions (perhaps affecting the degree of overlap between pollock and salmon). In this study, data on pre- and post-programme implementation were evaluated to determine if the programme is meeting stated goals and objectives or if modifications are needed. These evaluations included consideration of fleet-level bycatch numbers and rates, seasonality of bycatch by sector, and individual vessel bycatch rates. Results suggest that revised management regulations appear to have resulted in reduced bycatch of salmon overall. Also, lower bycatch rates seem to reflect changing behaviour in response to new management measures. However, the extent to which the programme is effective at the vessel level remains difficult to ascertain without explicit vessel-specific benchmarks developed for evaluating programme efficacy.

Keywords: Alaska pollock, bycatch, Chinook salmon, fishery management, incentives.

Introduction

The Bering Sea walleye pollock (*Gadus chalcogrammus*; known as Alaska pollock) fishery is one of the largest in the world, with the species contributing >40% to global whitefish production (Fissel *et al.*, 2013). The fishery is divided between a seasonal winter fishery ("A" season) that focuses on prespawning aggregations of pollock producing highly valuable roe (Ianelli *et al.*, 2013a) and a summer fishery ("B" season) extending from June to the end of October. The fishery is primarily pelagic, and catch of non-target species is very low, <1% of the total pollock catch (Ianelli *et al.*, 2013a). However, Chinook salmon (*Oncorhynchus tshawytscha*) are caught in significant numbers in some years (Figure 1). Chinook salmon have a designated status as a protected species under the groundfish fishery management plans in the North Pacific, with regulations implemented to ensure that all salmon caught incidentally as bycatch (Bycatch is defined under the Magnuson–Stevens Fishery Conservation and Management Act (2007) as "fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards". [16 U.S.C. 1802 Section 3 (2)] [MSA (2007)].) cannot be retained or sold. Catch of salmon species is designated as prohibited species catch (PSC) and is specified under the fishery management plans as a special category of bycatch. Some fraction of the salmon bycatch is donated to food

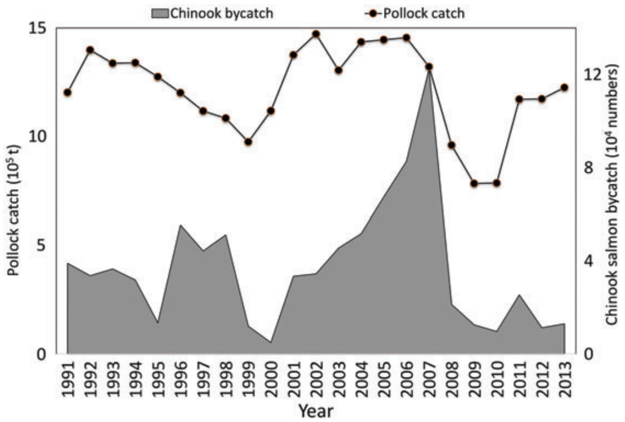

Figure 1. Time-series of Chinook salmon bycatch and pollock catch, 1991–2013.

banks using a third-party hunger-relief organization SeaShare. As of 2012, all salmon donated to the programme from fisheries in the Gulf of Alaska and Bering Sea are distributed within the State of Alaska (J. Harmon letter to E. Olson (NPFMC chair) April 2014 and Seashare.org). Genetic information indicates that the majority (~65%) of the Chinook salmon caught in the Bering Sea pollock fishery originate from a single geographic region encompassing several western Alaskan rivers, including a genetically distinct group from the Canadian portion of the Yukon River (Myers and Rogers, 1983, 1988; Guthrie and Wilmot, 2004; Myers *et al.*, 2004; Guyon and Guthrie, 2010; Guthrie *et al.*, 2012, 2013, 2014; Ianelli and Stram, this volume). Since Chinook salmon are a highly valuable, culturally important species in Alaska, and the resource is fully allocated to commercial and subsistence users, minimizing the bycatch of this species in other fisheries is a subject for management consideration (Witherell *et al.*, 2002; Stram and Ianelli, 2009). Western Alaskan Chinook populations have been depressed for several years causing extensive catch restrictions for communities dependent on the in-river availability of these resources, including a federal fisheries disaster declaration, virtual elimination of commercial harvest, and severe curtailment of subsistence harvests (Gisclair, 2009; Hilsinger *et al.*, 2009; Howe and Martin, 2009; ADF&G Chinook Salmon Research Team, 2013; Schindler *et al.*, 2013; ADF&G, 2014).

In response to heightened concerns over all sources of Chinook salmon mortality, and due to a high bycatch that occurred in 2007 (Figure 1), the North Pacific Fishery Management Council (NPFMC; also referred to here as "the Council") took further action to reduce bycatch in the pollock fishery by imposing (in 2011) revised management measures via Amendment 91 to the Bering Sea Aleutian Islands Groundfish Fishery Management Plan (NMFS, 2010). Previous bycatch restrictions for Chinook salmon had been addressed through time and area closures (Stram and Ianelli, 2009), but these measures did not minimize bycatch in all years. Consequently, new measures were developed that imposed limits on the Chinook salmon bycatch by fishery sector and season. The measures set limits to close fishing by sector and season, but also incorporated some improved flexibility by including a performance standard and promoting the creation of industry-proposed incentive programmes to further reduce bycatch below the performance standard. The plans, as reviewed by the Council, are designed to increase incentives for vessels to lower bycatch rates even in years when salmon encounters were low.

The Council and stakeholders requested an evaluation of the efficacy of the new measures at reducing bycatch and maintaining appropriate vessel-level incentives. This study examines the first 3 years of the management programme compared with patterns before programme implementation. Individual vessel-level patterns of bycatch over time as well as sector-level performance are evaluated to assess the performance of the programme as a whole, whether individual vessel behaviour with respect to bycatch avoidance has changed, and what additional measures might be considered for further improvements.

Methods

This analysis was prepared using data from the National Marine Fisheries Service (NMFS) catch accounting system, which relied on data derived from a mixture of production and observer reports as the basis of the total catch estimates. Total catch estimates were generated from information provided through a variety of required industry reports of harvest and at-sea discard, and data collected through an extensive fishery observer programme (Cahalan *et al.*, 2010). Data used in this analysis comprised sector and NMFS management area catch data by week as provided by NMFS Alaska Regional Office through their catch-accounting estimates. These data allowed comparisons by year and season for the inshore catcher-vessel fleet which delivers to shore-based processors ("catcher-vessel fleet" denoted CV), the offshore catcher-vessel fleet which delivers to floating processing platforms ("mothership fleet" denoted MS), and the offshore catcher–processor fleet (denoted CP) which catches fish and processes on-board (For purposes of this analysis, the community development quota fleet, the fourth AFA sector which receives pollock and Chinook allocations, is combined with the catcher processor fleet as their quota is leased to the CP fleet for harvesting and processing.). Rate-based (Chinook salmon per tonne of pollock) comparisons of data were made on multiple fleet scales across all years, months, and seasons to show distinctions among fleets as well as performance before and after programme implementation in 2011. In addition to fleet-level trends, direct NMFS observer programme data were queried to allow for vessel-level evaluations on fishing behaviour before and after programme implementation.

Evaluation of changes over time in individual vessel bycatch rates was compiled to indicate to what extent the management programme implementation was affecting individual vessel behaviour. The ability to display confidential vessel-specific bycatch was limited, thus some grouping of vessels was required. For this reason, after screening for catch levels as described below, vessels were selected by sector that had the five highest and five lowest bycatch rates to display their ranking changes over time. To further evaluate individual vessel performance within the sector, each vessel was ranked within each sector and year based on their average annual bycatch rate (Chinook salmon per tonne of pollock) relative to other vessels over the same time frame and sector. To avoid biasing the results by vessels that did not fish in some years, data were screened to omit vessels that caught <40 000 t of pollock for the period. For the shore-based catcher-vessel sector (only), this process was then repeated for comparison against the more recent years (2010–2013) as an approximation of whether individual vessel ranking had improved under the new management programme. Thresholds were defined for estimating when a vessel began fishing (25% of pollock quota) and when fishing was near completion (75% of pollock quota).

Results

Bycatch levels overall declined sharply following the historically high levels from 2004 to 2007 (Figure 1). While substantially lower than the highest years, current bycatch levels have been observed historically, particularly in the mid- and late-1990s (Note that in 2000, the fishery was not in operation for the entire year; thus, bycatch levels in that year are not viewed as representative of the trend.). Some correlation has been observed between overall western Alaska aggregate run sizes and bycatch levels in a given year (Ianelli and Stram, this volume). However, the highest bycatch years exceeded expectations, given run strengths, suggesting that other factors were involved. Here, we examined whether individual sector and vessel-level behaviour had changed following implementation of the bycatch management programme in 2011 (and for the catcher-vessel sector including the voluntary implementation in 2010). Given the seasonal nature of the fishery and observed monthly variation in bycatch rates, bycatch levels by season, month, and sector were examined for indications of changes in fishing behaviour.

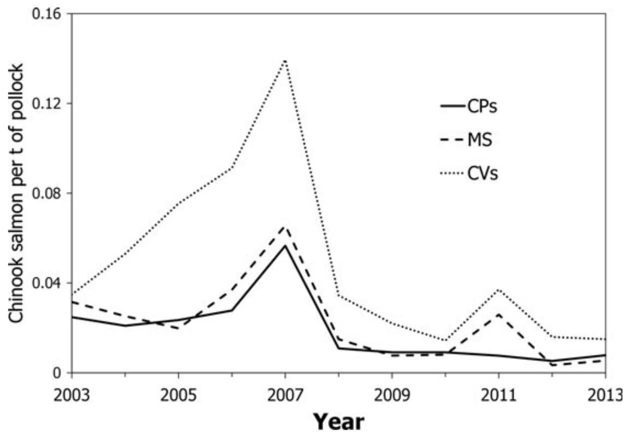

Figure 2. Trends in the annual bycatch rates by sector, 2003 – 2012. CP refers to catcher – processors, MS to motherships, and CV to catcher vessels that deliver to shore-based processors.

While there has been a general decline in rates overall since the 2004–2007 period, the rates have varied for some sectors in some months. This may reflect that, as the incentive programme began, some vessels changed their behaviour (e.g. fishing earlier) and others (perhaps poorer performing vessels) continued operations more similar to the *status quo* (Figure 2). By month, February, March, September, and October tend to have the highest rates and numbers across the fleet, with some differences among sectors. The highest numbers for CPs were sometimes in January, but more consistently in February and March for winter and September and October for summer–autumn (Table 1). In most years, the CP bycatch rates were higher in winter than in October except for 2003 and 2011, although for the latter, it was lower than

Table 1 Annual and monthly pattern of pollock fishery Chinook salmon bycatch rate (number per tonne of pollock).

	Month	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Catcher–processors	J	0.06	0.03	0.04	0.06	0.14	0.02	0.07	0.04	0.01	0.02	0.03
	F	0.10	0.03	0.05	0.06	0.14	0.04	0.01	0.03	0.01	0.01	0.02
	M	0.04	0.05	0.03	0.08	0.07	0.02	0.02	0.02	0.01	0.01	0.01
	J	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	J	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	A	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	S	0.05	0.02	0.03	0.01	0.03	0.00	0.00	0.00	0.01	0.00	0.00
	O	0.15	0.05	0.03	0.01	0.12	0.01	0.00	0.00	0.02	0.00	0.02
Mothership	J	0.07	0.02	0.03	0.08	0.21	0.11	0.05	0.00	0.02	0.05	0.03
	F	0.06	0.04	0.04	0.10	0.10	0.02	0.02	0.02	0.01	0.01	0.01
	M	0.05	0.05	0.03	0.09	0.05	0.03	0.01	0.02	0.01	0.00	0.01
	J	0.00	0.01	0.01	0.00	0.00		0.00	0.01	0.00	0.00	0.00
	J	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	A	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	S	0.02	0.02	0.02	0.00	0.04	0.01	0.01	0.00	0.01	0.00	0.00
	O	0.15	0.08	0.02	0.00	0.18	0.01			0.18		
Shore-based catcher vessels	J	0.05	0.04	0.04	0.12	0.41	0.12	0.32	0.15	0.01	0.02	0.02
	F	0.07	0.04	0.07	0.19	0.16	0.07	0.03	0.05	0.02	0.03	0.01
	M	0.05	0.06	0.03	0.06	0.04	0.02	0.01	0.01	0.02	0.02	0.02
	J	0.00	0.00	0.01	0.03	0.01	0.00	0.01	0.01	0.00	0.00	0.00
	J	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	A	0.00	0.02	0.03	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.01
	S	0.02	0.06	0.07	0.07	0.14	0.03	0.05	0.03	0.10	0.02	0.05
	O	0.13	0.35	0.44	0.20	0.46	0.22	0.04	0.19	0.24	0.08	0.13

Shading represents higher bycatch rates. Note effective pollock season closures are in April, May, November, and December. The mothership fleet did not fish in June 2008 and October 2009 – 2010, 2012 – 2013; thus these values are left blank.

in the same month in all but 2 previous years. For motherships, October 2011 was also anomalously high over the 2003–2012 time frame for number by month. By rate, October 2011 was the third highest since 2003. Rates for the mothership sector were generally highest in February and March as well as sporadically in October. For the shore-based CV sector, highest numbers were generally in January–March and September–October. However, for CVs, the October bycatch rate was high in many years unlike the anomalies observed, for example, in 2007 and 2011 for the other sectors. On average, rates in the shore-based sector were higher than in the other sectors across all years.

Given the indication of higher rates in the latter part of the B season, mean weekly bycatch rates by sector were examined for September and October (Figure 3). This shows that the fleet-specific pollock catches declined later in the season, but the Chinook salmon bycatch rate (Chinook salmon per tonne of pollock) increased. The pattern is similar for each sector, with the shore-based fleet showing the most dramatic increase, particularly from the middle of October onwards (Figure 3). A closer examination focused on the shore-based fleet and compared the recent years (2010–2013) when vessel-incentive programmes were effectively under way with the time-series including all the data. Results show that the shore-based incentive programme retained a similar seasonal pattern, but overall the rates declined considerably (Figure 4).

Another examination was to group five vessels with the highest bycatch rates (over the period) and similarly form a second group of the five vessels that had the lowest bycatch rates (by sector). An examination of their relative ranking over time indicated some variability within and between sectors, but changes were relatively minor, while the sectors as a whole reduced their bycatch by having lower rates (Chinook salmon per tonne of pollock); relative to other vessels within their sector, the changes were minor.

Individual vessel rankings within and between sectors showed a relatively large range of performance, with shore-based catcher vessels having much higher rates than other sectors (Figure 5). Given this, seasonal differences were evaluated for the shore-based fleet to understand factors that had affected bycatch rates. Results showed that winter "A" season rates were more similar to each other than the rates by vessels during the "B" season (Figure 6). While some vessels had both high winter and summer season rates, in general the vessels with the highest winter season bycatch rates ranked lower primarily because of their lower summer season bycatch rates. An individual vessel's relative ranking across all years appeared to be driven primarily by its rates in summer (Figure 6). In comparison with recent years, many of the best performing vessels historically retained their low ranks in recent years. More variability was seen in recent years across average vessels, while some worst performing vessels appeared to have improved their ranking relative to their historic performance (Figure 7). Some of the worst ranked vessels historically had remained in the lower third of the vessels considered in recent years as well.

Operationally, the decision regarding when to begin fishing in summer appeared to drive a vessel's relative rank (Figure 8). Vessels that began fishing earlier finished earlier in summer and had the lowest relative rank for Chinook bycatch. In contrast, those still fishing into October had higher rates and correspondingly consistently ranked worse. Some behavioural changes had been observed in the relative timing of fishing in these vessels since programme inception and an improvement in their relative ranking (Figure 8).

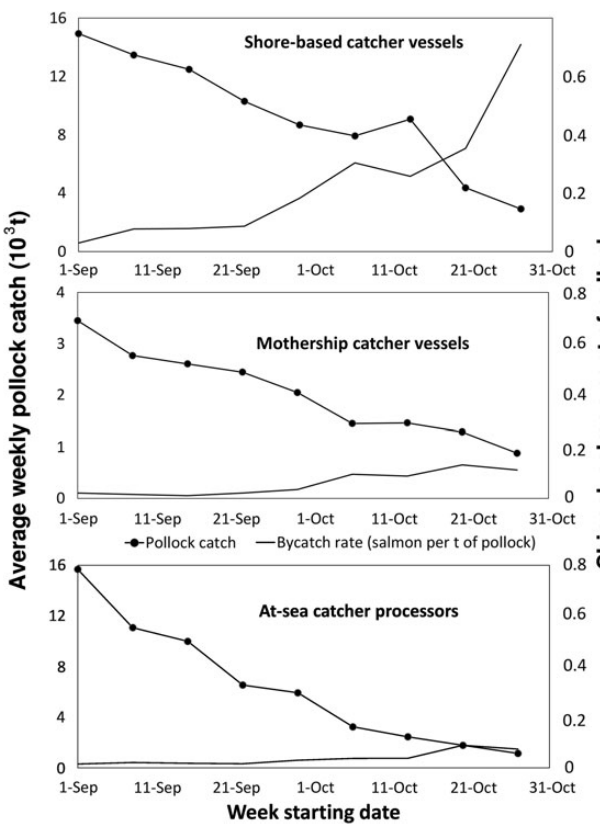

Figure 3. Average weekly pollock catch compared with Chinook salmon PSC rate (Chinook salmon per tonne of pollock) by sector from 1 September to 31 October 2003–2012.

Discussion

Overall, annual bycatch of Chinook salmon in the Bering Sea pollock fishery has been lower in recent years compared with historically high catch levels. However, the actual causes for this are unclear, but likely are a combination of fleet behaviour, environmental conditions, and low Chinook runs.

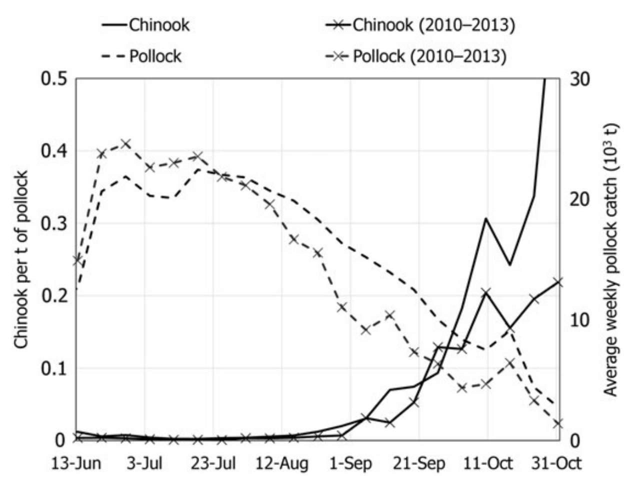

Figure 4. Detail of average Chinook salmon bycatch rates (left axis) compared with pollock catch by week for the "B" season for the shore-based catcher vessels by week, 2003–2013 compared with the period 2010–2013.

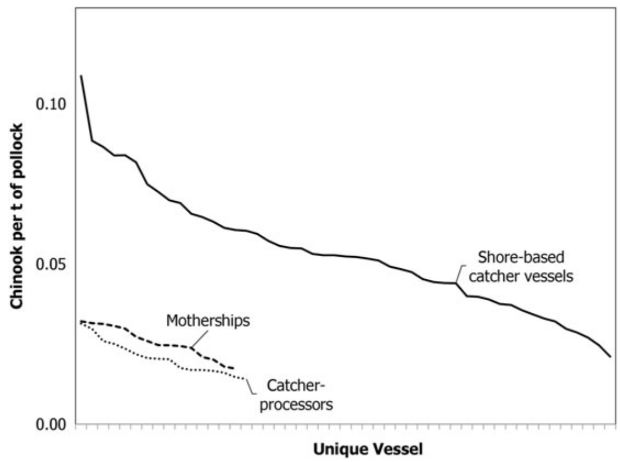

Figure 5. Chinook salmon bycatch rates by sector where vessels are ranked by "worst" performers to the left and "best" (lowest bycatch rates) to the right. There were 46 shore-based catcher vessels selected for this analysis (mothership and catcher–processor fleets are numerically smaller).

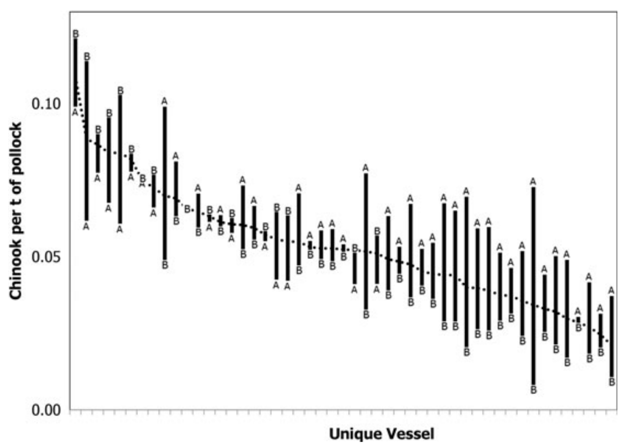

Figure 6. Aggregate annual (line) and "A" and "B" season bycatch rate over all years (2003–2013) for each of the 46 selected "shore-based" fishing vessels. Note that the "left-most" vessel had the highest bycatch of Chinook salmon for the period 2003–2013, whereas the right-most vessel had the lowest.

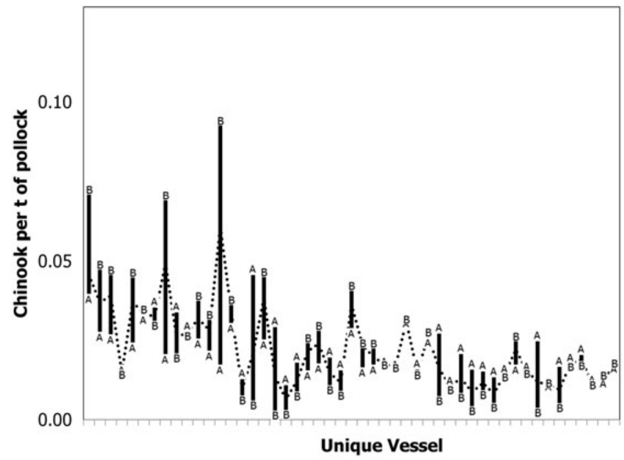

Figure 7. Aggregate annual (line) and "A" and "B" season bycatch rate over all years (2010–2013; the period when industry began effectively fishing with greater incentives to reduce bycatch) for each of the 46 selected "shore-based" fishing vessels. Note that the "left-most" vessel had the highest bycatch of Chinook salmon for the period 2003–2013, whereas the right-most vessel had the lowest.

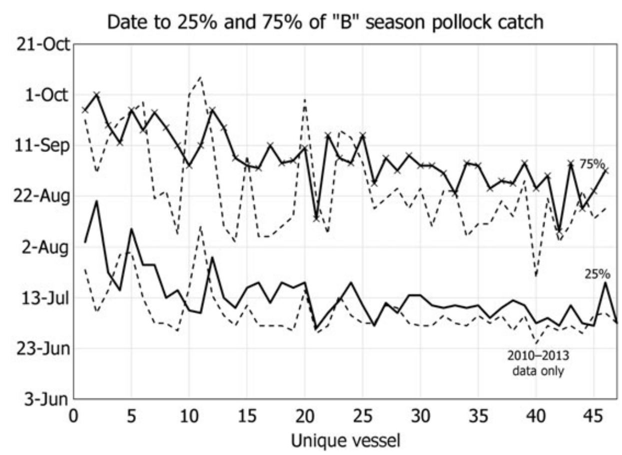

Figure 8. Average fishing dates when 25 and 75% of "B" season pollock catch was harvested by individual vessels for the entire 2003–2013 period and for the 2010–2013 period separately (for 25% of the pollock catch; dashed line).

The Bering Sea pollock fishery operations during winter tend to be concentrated in the generally ice-free southeastern area south of the Pribilof Islands, where most of the spawning aggregations occur (Ianelli *et al.*, 2013a). Catcher–processor and mothership-sector fishing operations occur in areas of limited ice cover, while shore-based catcher vessels are generally in more ice-free zones. Fishing effort overall tends to concentrate for all sectors in areas as ice cover increases (Pfeiffer and Haynie, 2012). The fleet is further impacted in winter by the spatial and temporal progression of spawning as winter focuses on pollock roe. Ice cover and roe-bearing fish availability limit the spatial extent of the winter fishery, which likely accounts for the more homogenous rates across fleet sectors during this season. During the ice-free "B" season period, the fishing area is greatly expanded, particularly for mothership and catcher–processor operations. Hence, fishers in these sectors have more flexibility when and where to fish and what the bycatch situation might be. In 2010, the year before the regulatory management programme was officially implemented, the shore-based catcher vessels initiated a trial of their incentive programme, which continued since that year. Some vessels clearly made different decisions when to begin fishing since that time to complete their quota before the late September–October known timing of higher Chinook rates. The incentive programmes designed by industry carry over from 1 year to the next; thus, performance in the previous summer impacts the availability of salmon quota for an individual vessel in the subsequent winter. However, some vessels appear maintaining behaviour that leads to higher bycatch rates in the latter portion of summer.

Since 2002, the fleet has also participated in voluntary measures to reduce Chinook bycatch, including a system of short-term closures based on real time bycatch information on "hot spots" communicated to the fleet as well as the development and use of escape panels in the trawlnet to allow salmon to escape without significant loss of pollock (Haflinger and Gruver, 2009; Gauvin *et al.*, 2010). Mechanisms such as those employed in the Bering Sea pollock industry to increase fleet-wide communication have been shown to be effective at bycatch reduction when accompanied by strong economic incentives in the fleet (Gilman *et al.*, 2006; Little *et al.*, 2014). Appropriate incentives have been further noted to increase the successful bycatch reduction in innovative technical devices (Squires and Vestergaard, 2013). The pollock fleet's continued efforts to both develop and employ salmon excluder devices in the fleet exemplify this concept (Gauvin *et al.*, 2003, 2013; AFA CV Intercooperative and Pollock Conservation Cooperative, 2006; Gauvin and Gruver, 2008; Gauvin, 2010). A survey of vessel operators indicated an increase in both the frequency of use of salmon excluders within individual vessels by haul as well as across vessels within the fleet (J. Gruver, J. Mize, and S. Madsen, pers. comm.). These voluntary measures have likely contributed to reduced bycatch in recent years; however, exact quantification of the bycatch reduction by these measures is not possible at this time due to lack of data, as vessels are not required to report the use of excluders.

Environmental effects also play an important role in the marine survival of juvenile salmon. In particular, sea surface temperatures (SSTs) may affect the growth and marine survival of juvenile western Alaska salmon, with colder SSTs reducing the availability of critical prey and leading to slower growth (Farley *et al.*, 2005). Temperature also appears a significant factor in regions of higher bycatch (e.g. Ianelli *et al.*, 2013b). Competition between salmon species at sea and carrying capacity may also limit growth and survival of salmon and impact population level returns (Ruggerone and Nielsen, 2009). Low western Alaska Chinook salmon runs in recent years is another indication of less salmon available in the ocean, but the extent to which this impacts the occurrence of Chinook in pollock trawlnets seasonally and annually is not well known, but likely plays an important role as well in years of lower bycatch.

In selecting a bycatch management approach that includes overall limits and provides for incentive programmes to remain below limits and stated performance goals (for a full description of the Amendment 91 programme, see http://www.alaskafisheries.noaa.gov/frules/75fr53026.pdf), the NPFMC examined analyses of the costs to the pollock industry of various cap levels and the related estimates of bycatch reduction to balance competing goals under the Magnuson–Stevens Act National Standards, namely National Standard 1 ("Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the U.S. fishing industry..." MSA (2007) § 301(a)(1), 16 U.S.C. § 1851(a)(1).) and National Standard 9 (NPFMC and NMFS, 2009). Detailed guidelines from NMFS exist for complying with National Standard 1; however, the guidelines for National Standard 9 ("Conservation and management measures shall, to the extent practicable, (A) minimize bycatch and (B) to the extent bycatch cannot be avoided, minimize the mortality of such bycatch" MSA (2007) § 301(a)(1), 16 U.S.C. § 1851(a)(9).) are less prescriptive (50 C.F.R. 600.310 seq.). The clear policy directive, however, by the NPFMC was that, regardless of cap levels, the intent was to reduce bycatch at all levels of salmon abundance and to thus create a mechanism for the fleet to have the incentive to do so.

The bycatch management programme includes explicit goals and objectives for the incentive plan agreement (IPA) to demonstrate. These include the following [50 C.F.R. 679.21(f)]:

(i) The incentive(s) that will be implemented under the IPA for the operator of each vessel participating in the IPA to avoid Chinook salmon bycatch under any condition of pollock and Chinook salmon abundance in all years.

(ii) The rewards for avoiding Chinook salmon, penalties for failure to avoid Chinook at the vessel level, or both.

(iii) How the incentive measures in the IPA are expected to promote reductions in a vessel's Chinook salmon bycatch rates relative to what would have occurred in absence of the incentive programme.

(iv) How the incentive measures in the IPA promote Chinook salmon savings in any condition of pollock abundance in a manner that is expected to influence operational decisions by vessel operators to avoid Chinook salmon.

The NPFMC is currently in the process of examining additional modifications to the programme to increase the incentive of all vessels to reduce bycatch at the end of the season.

Specification of operational goals and objectives has been recommended as an appropriate means to advance best practices and standards in bycatch management (Kirby and Ward, 2014). Many global recommendations for best practices in bycatch management are explicitly met in this programme, namely observer coverage and data collection, explicit performance standards, and adequate surveillance (Gilman, 2011). Clearly, on a fleet-level basis based on bycatch reduction below limits as well as the performance standard, the programme is performing as expected and meeting some of the stated goals and objectives. However, despite this framework and stated performance standard limit (below which the incentive programme bycatch must remain), there was no explicit mechanism or benchmark by which to determine whether the goals on a vessel-level basis to change behaviour and avoid Chinook "under any condition of pollock of Chinook salmon abundance in all years" are being met. Benchmarks to determine to what extent a vessel has modified behaviour would need to be established by which to evaluate the efficacy of the programme in a transparent manner on a vessel-level basis.

While overall bycatch in recent years has been low relative to historical levels, Chinook stock status remains a crisis in western Alaska, and all sources of mortality continue to be important. Information indicates that the relative impact rate of current bycatch levels by the pollock fishery on western Alaska aggregate river systems and the Upper Yukon River is low (Ianelli and Stram, this volume). There is, nonetheless, a continued interest by the Council in reducing salmon bycatch from all levels, particularly given the continued low returns to western Alaska Chinook stocks. Finally, there is a need to develop useful metrics to evaluate the performance of a management programme, particularly at the vessel level, towards the Council's goals.

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