Final Project Report:

An Empirical Investigation of the Intra-seasonal Utilization of Spatial Bycatch Information in the Alaskan Groundfish Fisheries

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This report is the second deliverable under contracts number 05-62 and 05-63 listed as PSMFC Job Number 587.03. This report is a supplemental document to the first deliverable called for under the contract, a manuscript entitled “Common Property, Information, and Cooperation: Commercial Fishing in the Bering Sea” by Kurt Schnier, Robert Hicks, and Alan Haynie. This report includes more details on the fisheries we study and supplements the manuscript submitted to the National Marine Fisheries Service and the Pacific States Marine Fisheries Commission on January 30, 2008. The manuscript is currently in the process of journal submission and may well change subject to comments and revision requirements. Upon final acceptance, we will submit the final reprint manuscript and citation information to the National Marine Fisheries Service and the Pacific States Marine Fisheries Commission for their records.

Introduction

The 1996 reauthorization of the Magnuson Stevens Fishery Conservation and Management Act (MSFCMA) states that one of its objectives is “to assure that the national fishery conservation and management program utilizes, and is based upon, the best scientific information available; involves, and is responsive to the needs of, interested and affected States and citizens; considers efficiency, draws upon Federal, State, and academic capabilities in carrying out research, administration, management, and enforcement, considers the effects of fishing on immature fish and encourages development of practical measures that minimize bycatch and avoid unnecessary waste of fish; and is workable and effective (16 U.S.C. § 1802 (2) 101-267, 104-297).” An important consideration of fisheries management is the issue of bycatch, defined by the Magnuson Stevens Fishery Conservation and Management Act 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 (3) 104-297). This research directly investigates a measure taken in the Alaskan Bering Sea to minimize bycatch- the creation of Sea State Inc. (hereafter Sea State). Utilizing a discrete choice model of fishermen behavior, we investigate the fleet’s intra-seasonal responses to bycatch information provided by Sea State. Our empirical results generate a different profile of spatial responses, depending on the groundfish fishery selected, with both a monotonically decreasing rate of aversion (rock sole fishery) and a U-shaped aversion pattern (yellowfin sole) being observed within these fisheries. Furthermore, our results indicate that there exists a fair amount of heterogeneity in the spatial responses of fishermen, which increases as the season progresses.

Bycatch often arises in complex multispecies assemblages where one species, or group of species, is targeted over another. This can have a deleterious effect on the larger ecosystem because it can alter the trophic web (Hall et al. 2000) and reduce the contemporaneous or future value of other fisheries. This later condition has been well documented in shrimp fisheries where juvenile fish and turtles are often captured in the seines of shrimp fishermen (Gallaway and Cole 1999; Reithe and Aschan 2004). Concerns about the impact of bycatch in global fisheries stimulated the Food and Agriculture Organization of the United Nations Code of Conduct for Responsible

Fisheries, which stated that nations should make concerted efforts to reduce bycatch and waste in fisheries (FAO 1995).

In a recent review of fisheries prosecuted within United State's waters, Harrington et al. (2005) estimated that approximately 1.06 million tons of fish were discarded in 2002 with an overall harvest of 3.7 million tons. The highest fishery-specific bycatch rate occurred within the Gulf of Mexico shrimp fishery where the ratio of bycatch to target fish was 4.56 (Harrington et al. 2005). The lowest rates occurred within the Alaskan fisheries. However, this must be put in perspective by the fact that roughly 22% of the total US bycatch occurs in Alaskan fisheries, due to the extremely high amount of fishing and product landed in Alaska (Harrington et al. 2005). For the fisheries studied in this analysis, Alverson et al. (1994) estimated that the bycatch ratio for Bering Sea flatfish fishery was 2.08. This fishery possesses an additional complexity which further highlights the bycatch issue. Fishermen operating within the Alaskan flatfish fishery operate under a two-tiered total allowable catch (TAC) regime, where TACs are defined over the target species as well as the bycatch species. In the event that the bycatch TAC is reached before the target species TAC, the fishery is prematurely shutdown with the possibility for a substantial amount of forgone economic rents due to the unharvested target species. This phenomenon will be discussed in more detail in the upcoming sections.

Due to the high bycatch rates observed within many fisheries and the ecological balance that must be maintained to efficiently manage our marine resources, substantial efforts have been made to reduce bycatch within fisheries. Efforts to reduce bycatch in fisheries have involved the utilization of bycatch reduction devices (BRDs), spatial closures, seasonal closures, and recently the introduction of fleet information systems (Gilman et al. 2006). Pascoe and Revill (2004) in their study of the European Brown shrimp fishery illustrated that the use of BRDs in the brown shrimp fishery would reduce the profitability of the brown shrimp fishery, but generate a more than offsetting return from the whitefish fishery. To investigate the use of spatial closures, Reithe (2006) examined whether or not the use of marine protected areas (MPAs) could be used to control excessive bycatch within the Barents Sea shrimp fishery. Results indicate that in an open access fishery it is possible to have a win-win situation in which the bycatch species is protected and the target species harvest increases. Bisack and Sutinen (2006) investigate the economic impacts of utilizing either season-port closures or individual transferable quotas (ITQs) to protect harbor porpoises, protected under the Marine Mammals Protection Act, in New England. Their results indicate that an ITQ program for harbor porpoises generates a cost savings from 5-12% over season-port closures depending on the targeted level of harbor porpoise protection. This later research finding may have an important impact on future policy development in Alaska. Currently, the Alaskan groundfish fishery is restructuring under Amendment 80 of the MSFCMA, which will transform these fisheries from a regulated open-access fishery (Homans and Wilen 1997) to a property rights management regime. Given that one of the primary bycatch species, halibut, is currently managed using ITQs, the question arises as to whether fishermen in the groundfish fleet will be allowed to hold halibut quota as well as groundfish quota.

Bisack and Sutinen's research suggest that there may be efficiency gains with such an arrangement and this may prove to be a fruitful extension for more research.

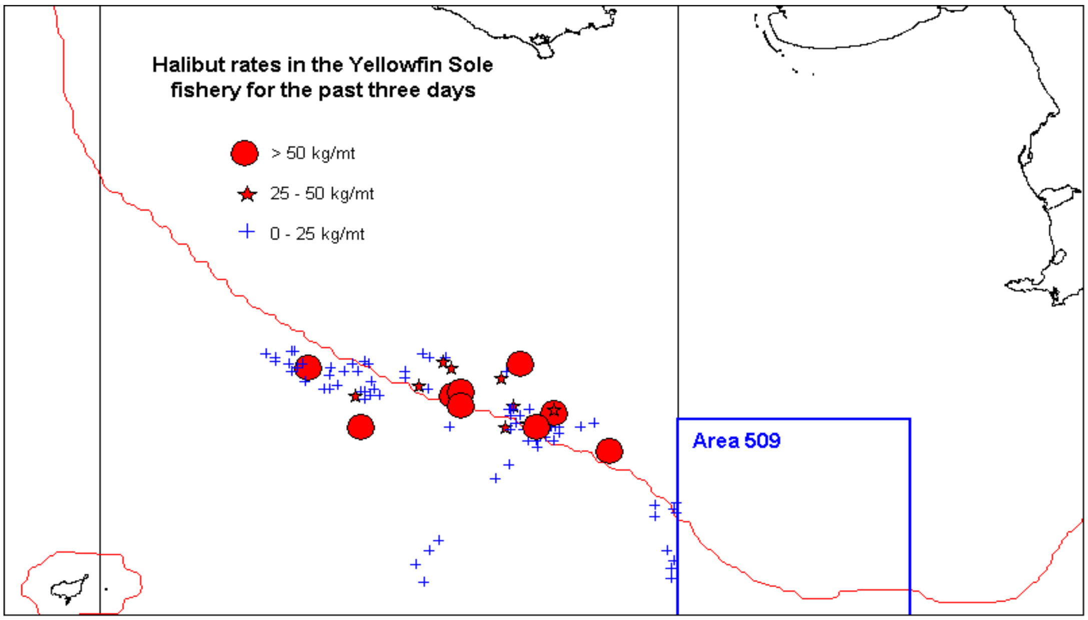
The use of fleet information systems to mitigate bycatch is the focus of this research project. Currently, these systems are being used in the US North Pacific and Alaskan trawl fisheries (the later the focus of this research), the Alaska demersal longline fishery, and the US North Atlantic longline swordfish fishery (Gilman et al. 2006). Fleet communication in the US North Atlantic began in 2001 as an experimental project to reduce loggerhead and leatherback sea turtle bycatch and ended in 2003 (Gilman et al. 2006). This experimental project combined fleet communication with the utilization of circle hooks, versus the standard J-hook design, and successfully reduced turtle bycatch by 50% (Gilman et al. 2006). The US Alaskan demersal longline fishery utilizes spatial information provided by Fisheries Information Services to reduce their halibut and seabird bycatch (Gilman et al. 2006). Although other bycatch reduction actions were enacted concurrent with information sharing, this system has substantially reduced the halibut and seabird bycatch within the Alaskan demersal longline fisheries (Gilman et al. 2006). The US Alaskan trawl fishery utilizes a similar information system as their counterparts in the demersal longline fishery, which is provided by Sea State. Given that this information system is the focus of this research, we discuss it in more detail in the following section.

Sea State Information

Within the Alaskan groundfish fisheries king crab, tanner crab, snow crab, pacific herring, pacific halibut, pacific salmon and stealhead trout are declared Prohibited Species Catch (PSC) (Witherell and Pautzke 1997). By definition PSC can not be sold by fishermen operating within the groundfish fishery. Therefore they have no real economic value, aside from the impact of fishing in areas associated with target and PSC species that my reduce the marginal costs of effort and perhaps discarding costs if too much PSC is caught. However, as referenced earlier, PSC TACs are established for groundfish fishermen which if exceeded will prematurely terminate the fishery. Within the Alaskan flatfish fisheries, a sub-set of the groundfish fleet, the most significant PSC species are Alaskan halibut and the different crab species. In an effort to reduce bycatch within the flatfish fishery, Sea Sate provides spatial bycatch reports for both of these species. The Alaskan halibut PSC is the primary focus of this research. This species is especially problematic because it prefers the same habitat as many flatfish species and is often caught while fishing for flatfish.

In the fall of 1995, Sea State first began providing spatial bycatch reports to fishermen operating within the Bering Sea flatfish fishery (Gauvin et al. 1995). The information used to generate the reports is obtained from the National Marine Fisheries Service (NMFS). NMFS collects federal observer data on all vessels which exceed 125 feet in length, which constitutes a bulk of the Alaskan groundfish fishery fleet. A portion of vessels smaller than 125 feet is also sampled under the observer program. Sea State collects the federal observer data from participating vessels and generates spatial bycatch rate reports which it disseminates to participating vessels within the fleet. Although not everyone participated in the program early on in the life of Sea State, currently nearly all vessels participate within the program. The spatial bycatch reports are sent to the vessels on weekly intervals with additional reports often being provided as the season progresses. Furthermore, Sea State and NMFS regularly report bycatch rates by vessel to enhance the information provided to the fleet, which may be used to exert coercive pressure on non-cooperators within the fleet.[1] Given this informational structure, there is a widespread impression across the industry that the Sea State program has been successful in reducing bycatch.

Figure 1:



(Courtesy of Sea State Inc.: Report issued on August 18, 2003)

An example of the spatial bycatch reports is provided in Figure 1. Each report graphically illustrates bycatch hotspots and regions in which bycatch rates are low. From this information fishermen can learn which locations should be avoided in an effort to prolong the exhaustion of the bycatch species TAC. The motivation for providing the spatial bycatch information to the flatfish fleet is to generate a higher degree of coordinated bycatch aversion in an effort to extend the target species season. However, the marginal incentives to avoid bycatch critically depend on the degree of spatial correlation between halibut and flatfish densities. If there is a high degree of spatial correlation present between target and bycatch species, an individual vessel may still wish to fish in areas which possess high bycatch rates because avoidance generates a public good for the rest of the fishermen within the fleet via an extended season. This complicates the degree of expected coordination within the fleet and, as pointed out by

[1] Sea State regularly provides vessel-specific daily bycatch rates during high-periods. NMFS also provides vessel-level rates on a weekly basis, but the published numbers are perceived by industry to be difficult to interpret when vessels are operating in multiple areas and targeting multiple species so there is additional value in the more regular Sea State reports. Sea State also talks to fishermen about particular high hauls and will elaborate on the rate information as part of the reports.

Gauvin et al. (1995), illustrates the problems associated with a common pool bycatch quota. This phenomenon will be investigated within this research effort by estimating an intra-seasonal behavioral response model to Alaskan halibut bycatch rates. This will be discussed in a later section. The following section discusses the fishery studied and the data set utilized in our analysis.

Fishery Description

In order to manage PSC within the Bering Sea, in-season fishery managers have utilized PSC TACs combined with time/area closures.[2] The PSC TACs are set equal to a pre-specified percentage of the overall TAC for each PSC's target fishery and allocated to the groundfish fleet at large. PSC TACs are often further divided across the target sub-species within the groundfish fishery (e.g. rock sole, yellowfin sole and Pacific cod) and into seasons in order to spread out the temporal distribution of bycatch. Once the PSC TACs are reached, in-season managers issue a fishery closure for the target species. These closures have resulted in a number of fisheries being prematurely terminated, forgoing a considerable portion of the target species TAC. For instance, over the time period studied in this research (2000-2004) the yellowfin sole fishery (one of the primary target species in the groundfish assemblage) was prematurely shut down due to exceeding their halibut PSC TAC in 2001, 2002 and 2003. In 2001 when the fishery was terminated over 20% of the yellowfin sole TAC was left un-harvested.[3]

This report focuses on trawling vessels that target groundfish in the Bering Sea, which are significantly constrained by PSC limits for halibut.[4] The primary species targeted in these fisheries are Pacific cod, yellowfin sole, flathead sole and rock sole.[5] These species are caught by a fleet that, depending on the targeted species, are opened and closed during the season as catch or bycatch caps are reached. To reflect these differences we partition our data set into three groups: those targeting Pacific cod, yellowfin sole and those targeting all other flatfish (which we refer to as 'flatfish'). Pacific cod is analyzed separately because it is not captured within the flatfish assemblage nor is it as dramatically affected by the halibut PSC TAC as the flatfish fisheries. Yellowfin sole is analyzed separately because it is the dominant flatfish species within the Bering Sea. Weekly targeting designations are based on NMFS specifications.

Many vessels operate in the Pacific cod, yellowfin sole and other flatfish fisheries. Vessels prioritize on different species depending on a variety of factors including (but not

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[2] There are significant additional concerns regarding seabirds for longliners within the BSAI. However, sea birds are not an issue for the bottom trawl fleet considered here.
[3] There has been some research conducted on the optimal allocation of bycatch TAC among sub-fisheries in the Bering Sea flatfish fishery. Larson et al. (1996) illustrates that a substantial portion of the halibut quota should be reallocated from the longline fishery to the Alaskan pollock fishery. Further results indicate that quasi-rents in the pollock fishery over the years 1991-92 could have been increased by 6-7% if the PSC TAC shares had been optimally defined (Larson et al. 1998).
[4] In the past crab bycatch has also constrained these fisheries, but protected areas have pushed the fishery off of high crab bycatch grounds.
[5] Several other species are also caught and marketed (e.g., Dover sole, rex sole) which are jointly considered as 'other flatfish.'

limited to) their previous experience, the species open for fishing, PSC limits, current output prices, contracts with customers, and fuel costs. There are two sub-classes of vessels operating within the Alaskan groundfish fisheries: catcher vessels (CVs) and catcher processors (CPs). CPs take longer trips that may last 2-4 weeks and process fish onboard, whereas CVs take trips that last only a few days and deliver to inshore processors. Pacific cod is targeted by both sub-classes whereas yellowfin sole and the other flatfish species are primarily targeted by CPs. Within our analysis we focus on CPs and CVs separately for the Pacific cod fishery and only CPs for the yellowfin sole and other flatfish fisheries because of the very small number of CVs targeting these species.

Catch and bycatch data for this analysis come from the Alaska Fisheries Science Center's Observer Program Database. Vessel trips that targeted Pacific code, yellowfin sole, flathead sole, rock sole and other flatfish are included in the model.[6] The Observer Program places observers on 100 percent of the days at sea for vessels which are greater than 125 feet in length and 30 percent of days at sea for those vessels less than 125 feet. Each data point represents a given haul made by a vessel while on a fishing cruise. Spatial data on fishing locations were used to calculate the distances from one haul to the next and from each haul to the centroid of areas that might potentially be chosen for sequential hauls. To complete the data set we obtained price information from CFEC fish ticket and Commercial Operator Annual Report (COAR) data. During 2000-2004, over 99% of the flatfish and yellowfin sole CP hauls were conducted by Sea State members. Due to these high percentages we have decided to only look at those CP vessels which were members of Sea State.

Table 1 illustrates the descriptive statistics for the Pacific cod, yellowfin sole and other flatfish fisheries over the time period studied (2000-2004). The mean revenue per a haul in the flatfish fishery is approximately 38% greater than that in the yellowfin sole fishery, while the Pacific cod revenue for both CPs and CVs is as much as six times greater than either. In addition, bycatch rates and quantities are consistently higher in the flatfish fishery than in the yellowfin sole fishery. Whereas the Pacific cod fishery (whether CPs or CVs) had the highest bycatch rates of any fisheries studied in this report. In terms of quantities of bycatch, the Pacific cod CVs look similar to yellowfin sole, and the flatfish fishery exhibits similar tendencies to Pacific cod CPs. On average, a flatfish or pacific cod CPs haul catches as much as 44% more halibut than a yellowfin sole or Pacific cod CV haul.[7] Aside from the disparity in revenues and bycatch rates and quantities within these two fisheries, on average fishermen in these in the flatfish and yellowfin sole visit a very similar number of spatial locations on a cruise (8.16 for the yellowfin sole and 7.32 for the flatfish fishery), suggesting a similar level of spatial mobility. The Pacific cod fleet fish, on average, make fewer site switches during cruises.

[6] For the 2000-2004 years included in this analysis, vessels are assigned a weekly target based on the composition of catch observed by onboard observers. We followed the methods employed by NMFS in-season managers in defining targets for calculating remaining target and bycatch TACs in the fisheries.

[7] Sea State relays bycatch information in terms of rates (tons of bycatch per haul as a percent of tons of catch haul) rather than raw quantities (tons of bycatch per haul). Flatfish hauls have an average bycatch rate that is 73% greater than yellowfin sole.

Table 1: Summary Statistics

Pacific Cod (CVs)	Mean	Std. Dev.	Min	Max
Haul Revenue	3,713.39	5,231.01	0	67,954.20
Bycatch (rates)	44.54	67.17	0	894.21
Bycatch (quantities)	295.83	577.21	0	12,839.60
Sites Visited per Cruise	3.07	2.30	1	17.00
Pacific Cod (CPs)				
Haul Revenue	2,379.88	5,457.04	0	70,418.48
Bycatch (rates)	42.00	55.04	0	970.14
Bycatch (quantities)	433.63	611.00	0	9,774.01
Sites Visited per Cruise	3.79	4.21	1	28.00
Yellowfin Sole (CPs)				
Haul Revenue	611.49	983.22	0	16,589.69
Bycatch (rates)	16.37	32.24	0	553.52
Bycatch (quantities)	285.20	667.98	0	14,463.10
Sites Visited per Cruise	8.16	4.93	1	32.00
Flatfish Fishery (CPs)				
Haul Revenue	719.71	1152.25	0	14,232.27
Bycatch (rates)	28.26	40.83	0	512.37
Bycatch (quantities)	410.82	679.59	0	13,086.00
Sites Visited per Cruise	7.32	4.65	1	30.00

Each year the North Pacific Fishery Management Council (NPFMC) approves PSC levels for the different sectors of the Alaskan groundfish fisheries, based on previously determined total PSC caps. These annual TACs for halibut, crab, herring, and salmon are set using historical biological information and are not adjusted annually based on stock or price information. NMFS tracks when fisheries approach and reach annual PSC TACs and provides regular information to the public about the status of fisheries, including the issuance of fishery closures. Figures 2 and 3 graphically illustrate the TAC and halibut PSC for Pacific cod, yellowfin sole and other flatfish fisheries and their actual catch of their respective target species and bycatch for the years 2000-2004.

For each observation in the dataset, we calculated the currently applicable PSC TAC and the quantity of the cap consumed at that point in the season. By moving each sectors' PSC between fleets or different species, NMFS in-season managers will make adjustments within the season to attempt to allow a larger amount of yellowfin sole and flatfish to be caught without exceeding the overall PSC TACs. These adjustments usually are made by re-allocating the Pacific cod PSC to the other groundfish fisheries. Therefore, in some years the flatfish fisheries are able to continue fishing beyond their PSC allowances without being prematurely shut-down. Through a careful investigation of the timing of these changes, we incorporate these adjustments into our analysis. Since this information is relayed through the fleet, both by Sea State and in-season management, fishermen are acutely aware of how binding bycatch TACs are at any given point in time. Knowledge of this is used to differentiate behavior into binding and non-binding years within the yellowfin sole and other flatfish fisheries, whereas Pacific cod is treated as the same regardless of year.

Figure 2:

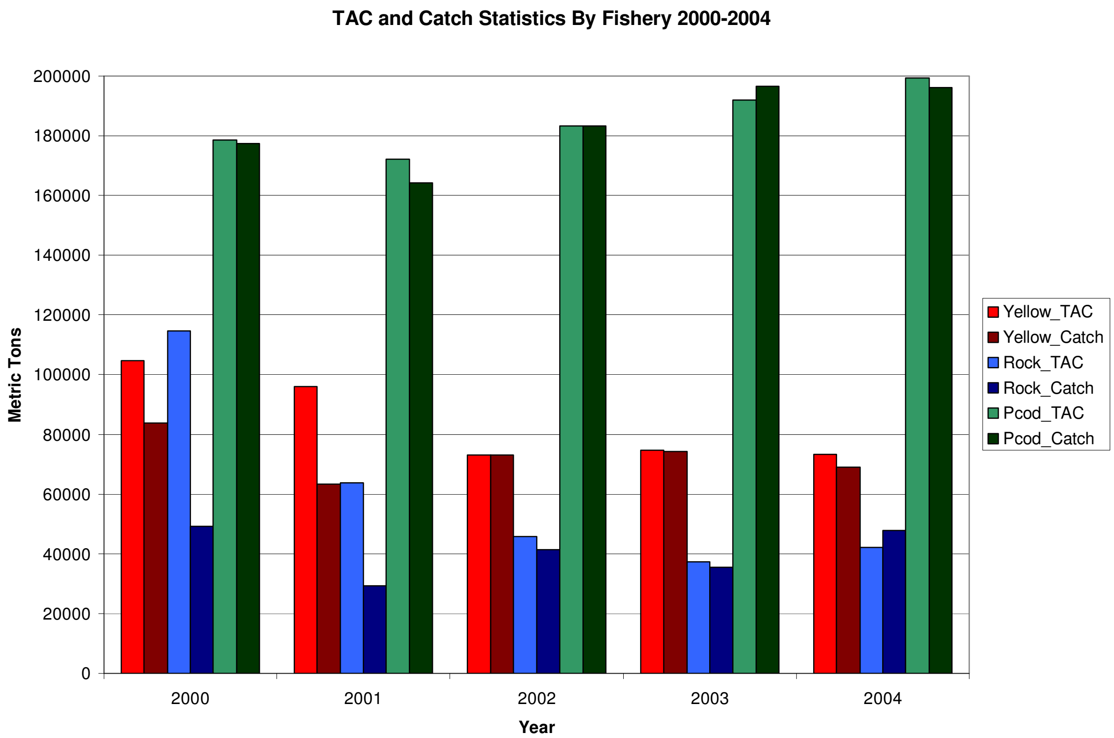
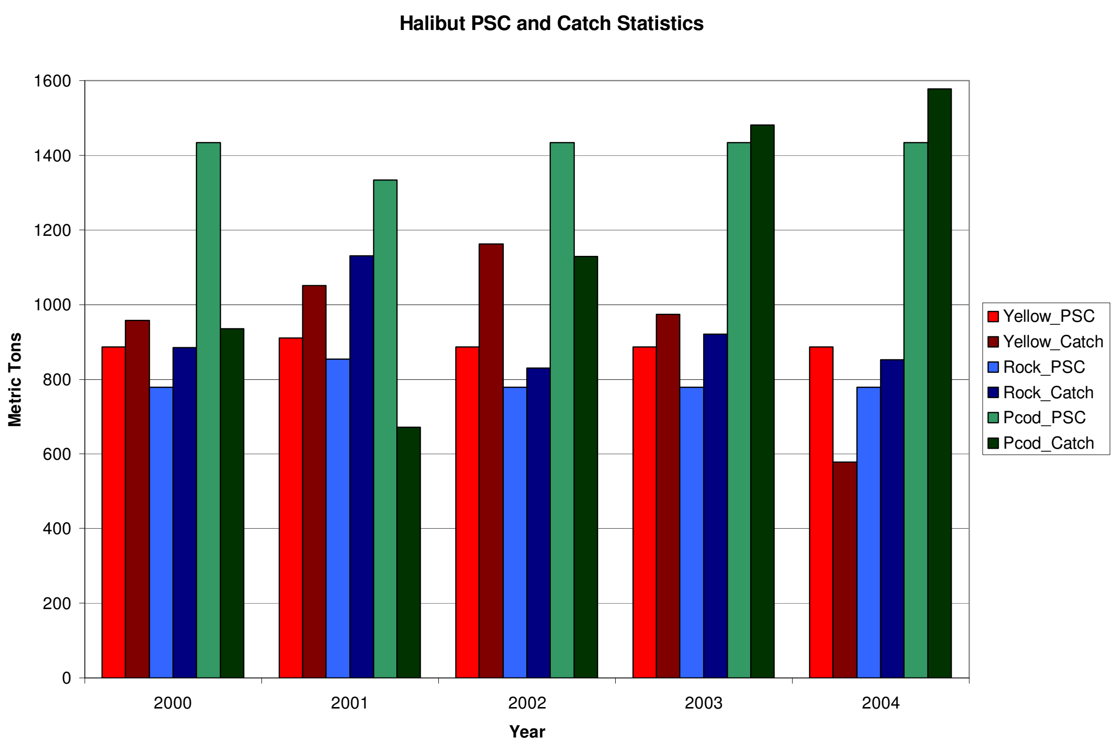


Figure 3:



Given that PSC TAC is often adjusted within the season to increase the amount which can be used in the yellowfin sole and other flatfish fisheries, Figures 4 - 6 graphically illustrate the evolution of the percentage of remaining allowable bycatch (Figure 4), average quantities of bycatch caught (Figure 5), and the average bycatch rate (Figure 6) for two representative years in the data set, 2000 and 2001, for the yellowfin sole and other flatfish fisheries.[8] Pacific cod is not illustrated because halibut bycatch is not as significant within this fishery. These two years were selected because in 2000 the yellowfin sole fishery was not prematurely shutdown whereas in 2001 it was. Following the opening of the yellowfin sole fishery in 2000 (top panel of each figure), the percentage of bycatch TAC remaining fell very slowly for nearly 14 weeks before the fishery was closed during July and then reopened in August. Following the reopening of the fishery the available bycatch remained high and the fishery was eventually shut down because the yellowfin sole TAC was reached. This behavior is consistent with the low bycatch quantities caught in this fishery during this time period (see Figure 5). However, the bycatch rates are similar to those in 2001 when the fishery was shut down for exceeding the yellowfin sole TAC. In 2001 the percentage of bycatch TAC remaining fell sharply from around week 12 through week 18. The fishery was again reopened in August and the bycatch levels fell relative to the earlier part of the season (see Figure 5), but dramatically increased toward the end of the season. The rapid rise in bycatch toward the end of the season was due to fishermen selecting to fish in high bycatch areas (see Figure 5) presumably because those regions also possessed a high amount of yellowfin sole which they wanted to capture before the fishery was shutdown.

In the flatfish fishery there was high bycatch for the first five weeks of the season in 2000, that steadily declined for the remainder of the season. Bycatch remained slightly above zero for some time and fell slightly below zero for an extended period of time late in the season. This behavior is consistent with high bycatch rates and quantities in the early part of the season and low rates toward the end. The percentage of bycatch TAC remaining is allowed to fall below zero by in-season management because the halibut PSC TAC is allocated to the sum of all groundfish species and often the yellowfin sole and flatfish fisheries exceed their fishery-specific allocation in each year. However, vessels are aware that when remaining bycatch TAC falls below zero, shutdown due to bycatch is imminent. This is usually made up by the Pacific cod fishery which traditionally does not exceed their bycatch allocations within the season. In 2001 the average bycatch quantities and rates in the flatfish fishery increased and peaked during the early part of the season. Although the bycatch percentage did remain high for the first 5 or 6 weeks of the fishery it was dramatically affected later in the year by the high quantities captured, further constraining the fleet's production behavior.

[8] The point estimates illustrated in Figures 2-4 were obtained by averaging the weekly percentages remaining, the quantities of bycatch caught per haul over the week, and bycatch rates per haul over the week.

Figure 4:

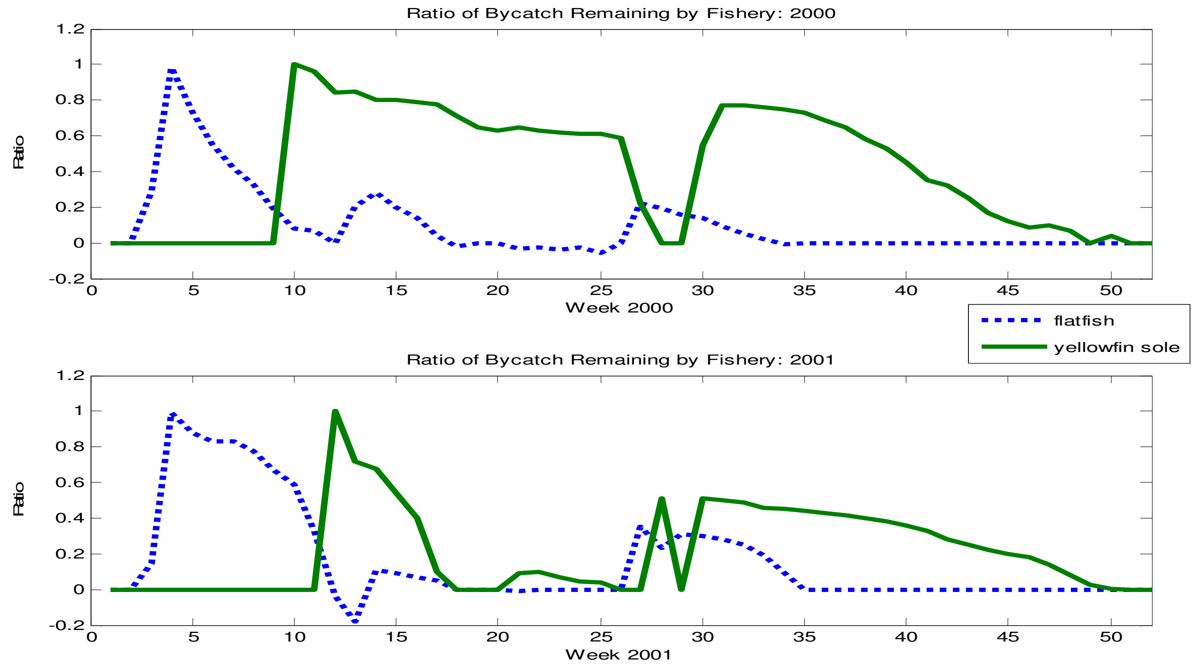


Figure 5:

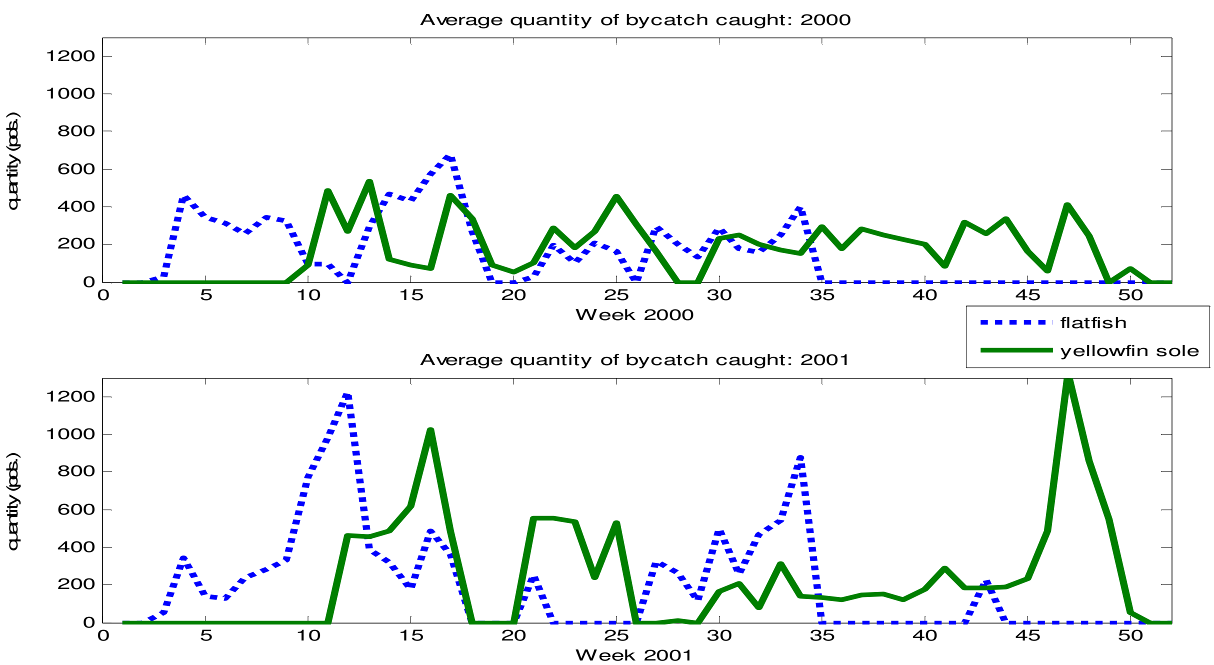
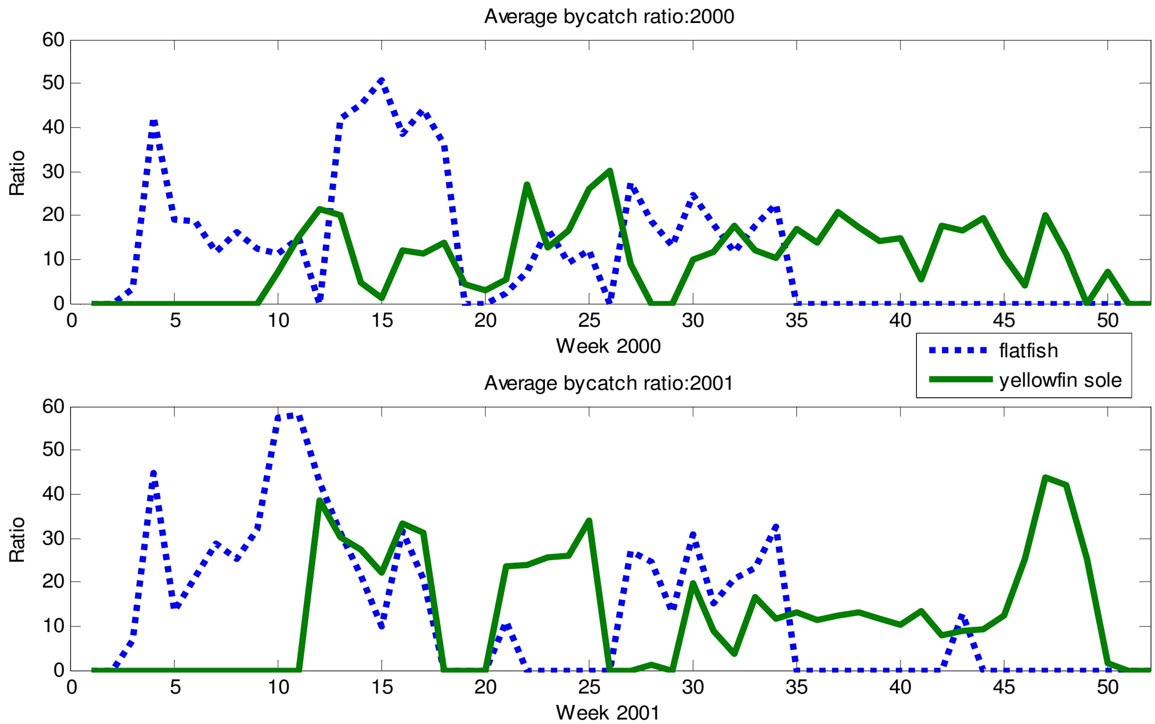


Figure 6:



One explanation for the differences between 2000 and 2001 is the degree to which the yellowfin sole/flatfish fisheries and halibut are compliments of production. Halibut and yellowfin/flatfish share similar habitat and perhaps those locations which possessed a high concentration of yellowfin and flatfish (the target species) in 2001 also possessed a high level of halibut, relative to that in 2000. Figures 5 and 6 support this hypothesis because the bycatch rates observed in 2000 and 2001 are similar, whereas the quantities of halibut caught in 2001 are substantially greater than in 2000.

Because structural differences in targeting behavior and halibut avoidance may exist for binding bycatch TAC years and non-binding years, we have partitioned the yellowfin sole and flatfish fishery data sets into binding and non-binding PSC years. Although PSC was binding in all years for at least one of the flatfish fishery seasons, it was not binding in the summer and fall seasons in 2003 and 2004 so we have elected to declare 2003 and 2004 as "non-binding" PSC years within the analysis despite the fact that it was binding in the winter and spring seasons. The yellowfin sole fishery, on the other hand, was non-binding in 2000 and 2004 for all sub-seasons within the year. Within the Pacific cod fishery we do not differentiate years based on the PSC TAC because it does not have as significant an impact on spatial behavior as it does in the yellowfin sole and other flatfish fisheries. Having discussed the general nature of the groundfish fisheries operating in the Bering Sea and Aleutian Islands (BSAI), the following section outlines the econometric model utilized to investigate how fishermen operating in these fisheries responded to the spatial information provided by Sea State over the course of the season.

Empirical Model

The empirical model used in this analysis is an intra-seasonal discrete choice model of spatial behavior within the Pacific cod, yellowfin sole and flatfish fisheries. Our definition of space within this model is the one-degree longitude by one-half-degree latitude statistical reporting zones used by the Alaska Department of Fish and Game (ADF&G). Within these groundfish fisheries fishermen make repeated discrete choices on where to fish at a given point in time. Given the discrete nature of their choices random utility modeling is conventionally used to model fishermen spatial behavior (Eales and Wilen 1986; Curtis and Hicks 2000; Holland and Sutinen 1999,2000; Smith and Wilen 2003) and we follow this paradigm with one exception; we utilize a mixed logit model (McFadden and Train 2000; Smith 2005) to allow for heterogeneous responses to spatial bycatch information where feasible.[9]

The foundation for our model rests on the commonly used random utility model (RUM) developed by McFadden (1974, 1978). Let the utility a fishermen on cruise i derives from fishing in location j on haul h be defined as,

$$v_{ijh} = x_{ijh}\beta_i + \varepsilon_{ijh} \qquad (1)$$

where x_{ijh} is a vector of individual, location and haul specific observations and β_i is an individual specific time-invariant preference parameter. The observation matrix, x_{ijh}, is observed by both the researcher and the fisherman but ε_{ijh} is only observed by the fisherman. The heterogeneous behavior parameters β_i are estimated by cruise within the yellowfin sole and "other flatfish" fisheries but not for the Pacific cod fishery. In the case of the Pacific cod cruises it is assumed that $\beta_i = \beta_j \forall i, j = 1,...,M$, where M is the number of cruises.[10] On cruise i a fisherman will choose to fish in site j on haul h if the utility of fishing in site j exceeds all other sites in the fishery on their h^{th} haul. This is denoted as,

$$v_{ijh} \geq v_{ikh}, j \in N, \forall k \in N. \qquad (2)$$

The error, ε_{ijh}, represents the unobserved (by the researcher) portion of site, haul and cruise-specific utility. For the yellowfin sole and flatfish fisheries if ε_{ijh} is assumed to be an independently and identically distributed Type I Extreme Value and $\beta_i \sim MVN(\tilde{\beta}, \Omega)$,

[9] Bockstael and Opaluch (1983) were the first to apply the RUM in the fisheries literature, but they did not use to investigate spatial behavior.

[10] Within the Pacific cod fishery we were unable to obtain sensible econometric results for the mixed logit models because the estimator would not converge. Therefore, we elected to report the results from a multinomial logit model instead.

we can recover the probability p_{ijh} that fisherman on cruise i selects location j on their h^{th} haul. This probability nests the multinomial logit model (MNL) within the multivariate integral of the distribution for β_i and can be expressed as,

$$p_{ijh} = \int \frac{e^{X_{jh}\beta}}{\sum_{k=1}^{N} e^{X_{kh}\beta}} \phi(\beta \mid \tilde{\beta}, \Omega) d\beta \quad . \tag{3}$$

Estimating the integral expressed in Equation 3 requires a simulation-based estimation algorithm which numerically approximates the integral using Monte Carlo simulation (Train 2003).[11] Within the Monte Carlo simulation D draws are made from the multivariate normal distribution with each draw producing a hypothesized value for p_{ijk}, denoted p_{ijk}^{d} where d indicates the d^{th} draw. In our analysis we used 200 Halton draws from the multivariate normal distribution. In addition, our individual identifier i was the cruise, which is a series of hauls conducted during a sequential time period.[12] There were 345 unique cruises within the yellowfin sole fishery and 233 in the other flatfish fishery. From these D draws a simulated likelihood function can be constructed,

$$L = \prod_{i=1}^{M} \prod_{h=1}^{H} \prod_{j=1}^{J} \frac{1}{D} \sum_{d=1}^{D} \left(p_{ijh}^{d}\right)^{Y_{ijh}} \tag{4}$$

where Y_{ijh} is equal to 1 if a fisherman during cruise i on haul h chooses site j, and equal to zero otherwise.

Maximum likelihood maximizes the log transformation of equation (4). For the Pacific cod fishermen the standard RUM was used to estimate their spatial discrete choices. In this case the utility a fisherman on cruise i derives from fishing in location j on haul h can be defined as,

$$v_{ijh} = x_{ijh}\beta + \varepsilon_{ijh} . \tag{5}$$

Assuming that the error structure is Type I Extreme Value the probability that the fisherman on the i^{th} cruise selects location j on their h^{th} haul can be represented as,

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[11] Our estimator was programmed in MATLAB with the foundational code provided by Kerry Smith and Dan Phaneuf.

[12] Unfortunately, the observer data does not explicitly specify the beginning and ending of cruises as usually defined in other fisheries. Consequently, we were forced to define cruises according to date gaps and assigned periods of sequential fishing as a cruise.

$$p_{ijh} = \frac{e^{X_{ijh}\beta}}{\sum_{k=1}^{J} e^{X_{ikh}\beta}} \tag{6}$$

which represents the MNL section of equation (3) expressed earlier. Maximum likelihood estimation proceeds by estimating the log transformation of the following equation,

$$L_{Pcod} = \prod_{i=1}^{M}\prod_{h=1}^{H}\prod_{j=1}^{J}\left(p_{ijh}\right)^{Y_{ijh}}. \tag{7}$$

In the case of Pacific cod observations are not partitioned into unique cruises because each observation is treated as independent from each other and no cross correlation structure is assumed. Repeated attempts were made to estimate equation (4) for the Pacific cod fishermen (both CPs and CVs) but we were unable to obtain reliable estimates because the estimator would not converge.

The specification of utility v_{ijh} in our empirical model is

$$v_{ijh}^{f} = \beta_1 Distance_{ijh|k} + \beta_2 \mathrm{Re}venue_{ijh} + \beta_{3i}(b_{ijh} * Dum\_tier\_1) + \beta_{4i}(b_{ijh} * Dum\_tier\_2)$$
$$+\beta_{5i}(b_{ijh} * Dum\_tier\_3) + \beta_6 Miss.Dum + \varepsilon_{ijh}$$

The superscript *f* denotes the sub-fishery within the fishery: Pacific cod catcher vessels (PCOD_CV), Pacific cod catcher processors (PCOD_CP), flatfish catcher processors (FLAT_CP) and yellowfin sole catcher processors (YELL_CP) respectively, further subdivided into binding and non-binding years.[13] The distance traveled from one's current location *k* to location *j* on the current haul *h* is captured by $Distance_{ijh|k}$ and is measured in kilometers. $\mathrm{Re}venue_{ijh}$ is the expected site specific revenues for haul *h* and is calculated using the seven-day moving average of site specific revenues observed over each of the respective sub-fisheries.

The bycatch information signal, denoted b_{ijh}, was specified two different ways to examine the way in which different information formats play into fishermen's decision making processes and all results are partitioned accordingly. The first form expresses the information as the expected site- and time-specific bycatch *rates*, where the rate is the ratio of expected bycatch to the expected catch of the primary target species. This treatment is utilized to capture the information provided by Sea State as the spatial bycatch information provided is expressed in rates (see Figure 1). The second treatment expresses the information as raw *quantities* of expected site and time-specific bycatch. Both the rates and quantities are calculated using seven-day moving averages for each

[13] The Pacific cod data was not further subdivided into binding and non-binding years because it many years it is not binding and in those years when the PSC TAC was exceeded the TAC for the target species was nearly all caught (see Figures 2 and 3).

site within the fishery. Seven-day moving averages were selected because this closely mimics the weekly intervals used by in-season management when declaring the available bycatch TAC remaining.

These two treatments are selected to test whether or not the spatial responses exhibited by fishermen in these fisheries differed depending on the type of spatial bycatch information assumed to be in their possession. Given that the bycatch TAC is expressed in raw quantities it seems rational that vessels may not respond to bycatch as characterized by rates in the same manner as quantities. For instance, if one were to catch 100 pounds of halibut and 100 pounds of flatfish in a location the ratio would be 1. A similar ratio would be obtained if the quantities were 1 metric ton of halibut and flatfish respectively, but the second state would have a more adverse consequence on the flatfish season length. Alternatively, it is possible that a fisherman could infer his expected bycatch quantity if he combines the rates information with his individual expectations on spatial target species catch rates. This may be increasingly important if the fleet's production levels are highly heterogeneous. However, we leave the relative role of these two forms of information on spatial behavior to be empirical determined within the econometric model.

To investigate the intra-seasonal spatial response of vessels to bycatch information, we utilize three different dummy variables interacted with the bycatch signal, b_{ijh}. The dummy variables were selected to partition the fishery's data set into roughly 1/3 intervals for each of the three respective groundfish fisheries. Table 2 indicates the percentage intervals used for the three groundfish fisheries with binary variables used to indicate whether or not the remaining PSC TAC fell within the respective ranges for each fishery.

Table 2: Dummy Variable Descriptions

Fishery	Dum_tier_1	Dum_tier_2	Dum_tier_3
Pacific Cod CVs	PSC > 50%	50% ≥ PSC > 20%	PSC ≤ 20%
Pacific Cod CPs	PSC > 50%	50% ≥ PSC > 20%	PSC ≤ 20%
Yellowfin CPs	PSC > 60%	60% ≥ PSC > 30%	PSC ≤ 30%
Flatfish CPs	PSC > 50%	50% ≥ PSC > 0%	PSC ≤ 0%

Each interval of PSC remaining captures a different time period within the fishery during which a fishermen's perception of their individual impact on the remaining PSC TAC may vary. The last time period within each fishery is chosen to capture a period where fishery shut-down is approaching or when the in-season management group makes small transfers in the bycatch TAC from one fishery to another in order to prolong the fishery. In either case, fishermen know that the bycatch TAC is potentially binding in the near-term and that shutdown is perhaps imminent. The final variable used in the analysis, $Mis.Dum$, takes a value of one whenever the expected location and haul specific estimates of revenues are zero because no fishing activity has taken place in that area over the past seven days. Regression results are displayed in Tables 2 and 3 for the yellowfin sole and flatfish fisheries respectively. Model 1 results utilize bycatch rates and Model 2 results use bycatch quantities.

Utilizing the three thresholds for the percentage of bycatch remaining facilitates the analysis of the fishermen's behavioral responses when the bycatch TAC becomes more binding on fleet behavior, where binding is defined as less PSC TAC remaining.[14] A statistically significant negative coefficient on any of the intervals would indicate the avoidance of areas with a higher spatial bycatch rate or quantity, depending on the model selected, whereas a positive coefficient would indicate the opposite. Furthermore, utilizing the two forms of bycatch information and partitioning the data into binding and non-binding years in the analysis allows us to investigate whether or not vessels possess asymmetric response functions to the two potential ways of characterizing bycatch (recall that Sea State reports rates) as well as the state of remaining PSC bycatch TAC. The next section will summarize the results obtained from the empirical models estimated.

Results

In total, twelve different empirical models were estimated to investigate the intra-seasonal responses to bycatch information within the Alaskan groundfish fisheries. To simplify the discussion of our empirical results we will examine the rates and quantities models separately for each of the two Pacific cod models (CPs and CVs), the yellowfin sole and the other flatfish fisheries. Each of these models use the tiering of the remaining PSC TAC expressed in Table 2 as well as the binding and non-binding designations for the yellowfin sole and other flatfish fisheries discussed earlier. A more detailed discussion of our empirical findings can be found in the manuscript submitted to the National Marine Fisheries Service as part of this contract. First we will discuss the empirical results using the bycatch rates information because it more closely mimics the information provided by Sea State to the groundfish fleet.

Rates Results

The results for each of the six sub-fisheries using the bycatch rates information are contained in Table 3. A number of common results hold across the six models estimated using the bycatch rates information. The distance traveled from one location to another has a strong negative effect on one's site visitation probability, the expected revenues derived from a location have a large positive effect on the probability and the probability of site visitation decreases if the site has not been recently visited by the fleet. Aside from these commonalities the different sub-fisheries possess a number of cross similarities and differences that warrant a more detailed discussion.

The multinomial logit results for the Pacific cod fishermen indicate that the CV and CP fishermen possess different profiles of spatial response to bycatch rates. CV fishermen possess an inverted U-shaped behavioral response to spatial bycatch rates. Early in the

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[14] Alternative thresholds were experimented with in our preliminary analysis. Our tiering of the remaining bycatch TAC allows us to focus on the end of the season dynamics within the fishery and the fishermen responses to bycatch information during these respective time periods.

season when the remaining PSC TAC is greater than 50% they avoid regions with high bycatch rates, but as the season progresses, PSC TAC between 50% and 20%, they no longer avoid high bycatch rates (the parameter is not significantly different from zero). Their apparent lack of bycatch aversion when the remaining PSC TAC is between 50% and 20% is reversed when it is less than 20%. In this time period CV fishermen in the Pacific cod fishery possess a mean aversion rate that is nearly 3-times that observed early in the season. On the other hand, the Pacific cod CP fishermen do not possess an inverted U-shaped intra-seasonal bycatch aversion response. The only time period during the season in which they possess a statistically significant propensity to avoid bycatch is when the remaining PSC TAC is greater than 50%, beyond that their mean aversion rates are not statistically significant from zero.

Table 3: Empirical Results Using Rates Information: *Mean, Standard Deviation* and *t-stat*

Coefficient/Fishery Model	PCOD CV	PCOD CP	YELL CP *Binding*	YELL CP *Non-Binding*	FLAT CP *Binding*	FLAT CP *Non-Binding*
$Distance$	-14.49**	-18.86**	-38.64**	-37.53**	-30.79**	-35.53**
	(-55.8) [a]	(-80.0) [a]	(-128.8) [a]	(-97.7) [a]	(-104.6) [a]	(-63.3) [a]
$Revenues$	0.113**	0.049**	0.107**	0.036	0.255**	0.191**
	(25.34) [a]	(14.46) [a]	(5.96) [a]	(1.56) [a]	(12.05) [a]	(7.79) [a]
Dum_Tier_1	-4.976**	-3.390**	-5.470**	-17.286**	-3.711**	-18.134**
	(-8.55) [a]	(-5.92) [a]	(-2.03)	(-6.70)	(-3.62)	(-6.53)
$std.deviation$	-------	-------	10.910**	15.409**	2.705	6.601**
	-------	-------	(3.53)	(7.53)	(1.63)	(3.00)
Dum_Tier_2	-0.316	-0.610	-14.354**	-18.197**	-1.863	-15.577**
	(-0.30) [a]	(-0.93) [a]	(-8.91)	(-4.61)	(-1.07)	(-5.86)
$std.deviation$	-------	-------	10.875**	25.498**	12.291**	11.689**
	-------	-------	(6.45)	(10.47)	(6.77)	(3.96)
Dum_Tier_3	-14.19**	0.070	-13.257**	-14.901**	5.804	-13.463**
	(-6.03) [a]	(0.05) [a]	(-5.84)	(-2.91)	(0.73)	(-6.11)
$std.deviation$	-------	-------	18.812**	20.799**	76.921**	12.436**
	-------	-------	(7.53)	(5.20)	(16.45)	(5.98)
Mis.Dum.	-2.806**	-2.208**	-1.9160**	-1.777**	-1.531**	-2.009**
	(-50.9) [a]	(-57.4) [a]	(-46.5) [a]	(-35.9) [a]	(-32.2) [a]	(-24.4) [a]
Number of Obs.	7998	9736	16,715	10,220	12,517	5,399
Log(L_0)	-29,093	-42,291	-72,822	-44,526	-54,042	-23.310
Log(L_1)	-13,819	-17,508	-26,015	-15,497	-17,862	-7,398
Like. Ratio Index	0.525	0.586	0.643	0.652	0.669	0.683

(* indicates significant at 90% level, ** indicates significant at the 95% level)
([a] indicates that the parameter is not a random parameter)

Combined these results suggest that spatial bycatch information does not have a strong influence on CP fishermen behavior except for early in the season, while for the CV fishermen there is evidence of statistically significant and increasing bycatch aversion from the early to late season period. However, it is important to note that we only possess observations for 30% of the CV fishermen whereas we have complete coverage for the CP vessels. Therefore, we can not confidently conjecture whether or not the differences in spatial responses to bycatch rates is indicative of all CVs and CPs. However, the lack of statistically significant coefficients on bycatch rates for half of the parameters in the Pacific cod models indicates that it is not as strong an influence of spatial behavior as it is within the yellowfin sole and other flatfish fisheries. This is consistent with the fact that PSC bycatch quotas do not restrict fishermen behavior in the Pacific cod as much as it does within the yellowfin sole and other flatfish fisheries.

The mixed logit parameter estimates illustrate that the yellowfin sole fishery exhibits an intra-seasonal U-shaped response curve to the avoidance of areas with high bycatch rates. Although all the intra-seasonal responses are negative, the greatest rates of avoidance occur when the remaining PSC TAC is between 60% and 30%. Furthermore, the mean aversion rates for the binding PSC TAC years (2001, 2002 and 2003) are lower than those in non-binding years (2000 and 2004). However, given that one can not reject the null hypothesis that the mean aversion rates in the binding and non-binding years are identical when the PSC TAC is below 30 percent, the rates of bycatch aversion appear to be roughly consistent at the lower PSC TAC levels.[15]

The bycatch aversion behavior in the flatfish fishery is substantially different from that in the yellowfin sole fishery. The intra-seasonal mean spatial responses are not U-shaped, but are monotonically increasing as the remaining PSC bycatch TAC decreases in both binding and non-binding years. This indicates that the degree of bycatch aversion decreases throughout the season. Furthermore, there are substantial differences in the mean spatial responses in binding and non-binding years, with non-binding years consistently illustrating more bycatch aversion. In addition, in all cases one can reject the null hypothesis that the mean spatial responses are identical across both models (binding vs. non-binding years). In binding PSC bycatch-TAC years fishermen avoid areas with high bycatch rates whenever the TAC is greater than 50% and otherwise appear, on average, to be non-responsive to bycatch rates because all the other mean parameter estimates are not statistically significant from zero. In non-binding years fishermen exhibit a strong propensity to avoid areas with high bycatch rates, which decreases as the remaining PSC bycatch TAC decreases. In addition, for virtually all parameters in the models, the standard deviation of the parameter estimates increase as the PSC bycatch TAC becomes more binding indicating that vessel specific responses to bycatch rates becomes increasingly heterogeneous as the PSC bycatch TAC decreases.

Quantity Results

The results from each of the six sub-fisheries using expected bycatch quantities information is contained in Table 4. The coefficients on the distance traveled from one location to another, the expected revenues derived in each location, and the dummy variable indicating whether or not the site had been recently visited are of the same sign, magnitude and significance as those obtained in the rates models (see Table 3).

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[15] A t-test was conducted to determine whether or not the aversion parameters were statistically significant from each other.

Therefore, the two bycatch information treatments possess some logical consistencies. However, there are a few differences that warrant further discussion.

Table 4: Empirical Results Using Quantities Information: *Mean, Standard Deviation* and *t-stat*

Coefficient/ Fishery Model	PCOD CV	PCOD CP	YELL CP *Binding*	YELL CP *Non-Binding*	FLAT CP *Binding*	FLAT CP *Non-Binding*
$Distance$	-14.41**	-18.83**	-38.94**	-37.86**	-47.95**	-36.31**
	(-55.6) [a]	(-79.9) [a]	(-129.9) [a]	(-98.6) [a]	(-101.3) [a]	(-65.3) [a]
$Revenues$	0.118**	0.051**	0.155**	0.037	0.280**	0.260**
	(29.93) [a]	(15.12) [a]	(8.32) [a]	(1.48) [a]	(10.5) [a]	(10.8) [a]
Dum_Tier_1	-0.985**	0.120**	-0.316**	-0.525**	0.5214	-1.036**
	(-12.8) [a]	(2.71) [a]	(-2.00)	(-3.70)	(1.27)	(-4.12)
$std.deviation$	-------	-------	0.562**	1.189**	0.995*	0.710**
	-------	-------	(2.86)	(5.83)	(1.82)	(2.78)
Dum_Tier_2	-0.271	0.230**	-0.465**	-0.642**	0.2422	-0.830**
	(-1.62) [a]	(4.00) [a]	(-4.66)	(-2.75)	(0.73)	(-4.84)
$std.deviation$	-------	-------	0.797**	1.382**	0.839**	0.565**
	-------	-------	(7.43)	(9.25)	(6.18)	(2.84)
Dum_Tier_3	-2.137**	0.339	-0.265**	-0.350	0.885	-0.777**
	(-6.07) [a]	(1.36) [a]	(-2.74)	(-1.25)	(0.27)	(-4.75)
$std.deviation$	-------	-------	-0.747**	1.156**	4.500**	0.814**
	-------	-------	(-6.35)	(5.22)	(3.31)	(4.31)
Mis.Dum.	-2.876**	-2.054**	-1.7463**	-1.673**	-1.330**	-1.771**
	(-53.1) [a]	(-55.63) [a]	(-44.3) [a]	(-34.3) [a]	(-24.0) [a]	(-22.4) [a]
Number of Obs.	7,998	9736	16,715	10,220	12,517	5,399
Log(L_0)	-29,093	-42,291	-72,822	-44,526	-54,042	-23.310
Log(L_1)	-13,760	-17,515	-26,127	-15,571	-17,836	-7,435
Like. Ratio Index	0.527	0.586	0.641	0.650	0.670	0.681

(* indicates significant at 90% level, ** indicates significant at the 95% level)
([a] indicates that the parameter is not a random parameter)

In general the Pacific cod parameter estimates for the CVs and CPs are very similar to those obtained in the rates model. In fact the parameter estimates for the CVs generate a nearly identical profile of spatial response to bycatch quantities as it did for the rates model, controlling for the magnitude of the coefficients in the models relative to information provided. This is not entirely true for the CPs because they possess a positive and statistically significant coefficient on bycatch quantities when the PSC TAC is greater than 50% and also when it is between 50% and 20%. This indicates that CPs actually prefer to fish in regions which possess a higher amount of bycatch until the end of the season nears. This behavior may be rationalized by the fact that the PSC TAC is not nearly as binding in the Pacific cod fishery as it is in the yellowfin sole and other flatfish fisheries. Whereas, as the season progresses and some PSC TAC is shifted out of the Pacific cod fishery and into the yellowfin sole and other flatfish fisheries their propensity to fish in areas with higher bycatch quantities dissipates to a point at which they are ambivalent (the coefficient not statistically significant from zero).

The parameter estimates for the yellowfin sole fishery using bycatch quantities are similar to those obtained in the rates model. They both possess a U-shaped behavioral response, however in both the binding and non-binding models the magnitude of the aversion parameter when the remaining PSC TAC is below 20% is substantially lower in the quantities model than in the rates model. In the binding years model the coefficient is negative and statistically significant which is similar to the rates model. However, in the non-binding years model the coefficient is not statistically significant from zero, which is substantially different from the large negative coefficient observed in the rates model. Combined these results indicate that although yellowfin sole fishermen possess a strong aversion to areas with a high rate of bycatch they do not behave as strongly when it comes to quantities of bycatch.

Another difference that exists between the rates and quantities models in the yellowfin sole fishery is the degree of heterogeneity present. In the quantities models the degree of behavioral heterogeneity is similar across the different tiers of remaining PSC TAC whereas there are substantial differences in the degree of heterogeneity present in the rates models where heterogeneity levels are clearly at their lowest when the remaining PSC TAC is greater than 50%. This indicates that the distribution of fishermen's spatial responses to bycatch quantities is relatively similar whereas in the rates models the distribution varies depending on the remaining PSC TAC. This is an important distinction given that rates information is provided by Sea State. This difference may be driven by heterogeneous expectations about the catch that the fisherman uses to calculate expected bycatch quantities.

Within the other flatfish fisheries the parameter estimates for the quantities models indicate that there are number of similarities across the models. The most striking similarity is that both the rates and quantities models for the binding years possess a very high degree of heterogeneity in the behavioral responses when the remaining PSC TAC is less than 0%. In addition, both the rates and quantities models coefficients when the remaining PSC TAC is less than 50% are not all statistically significant from zero in the binding year models. Combining this with the high degree of heterogeneity present indicates that both models predict a nearly identical number of vessels which avoid high bycatch zones (either rates or quantities) as those which actively target these regions.

In the non-binding years the parameter estimates for the other flatfish fisheries are for the most part very similar. Both the rates and quantities models indicate that aversion rates are monotonically decreasing, although still present, as the season progresses and the remaining PSC TAC decreases. Furthermore, both the rates and quantities models indicate that the degree of behavioral heterogeneity is greatest when the remaining PSC TAC is less than 0%. However, the magnitude of the behavioral heterogeneity is not nearly as large as within the binding years models. Combining this with the significant negative coefficients in non-binding years indicates that still a majority of the individuals within the fishery actively avoid high bycatch rate and quantity regions.

Conclusions

The results from our investigation indicate that fishermen in the Pacific cod, yellowfin sole and other flatfish fisheries predominately avoid regions which possess high bycatch rates and quantities early in the season. However, as the season progresses fishermen in all three fisheries reduce their degree of aversion. This reduction is greatest in the Pacific cod CP fishery where zero aversion is observed in both the rates and quantities models. In fact behavior within both Pacific cod fisheries is not the same as within the yellowfin sole and other flatfish fisheries. This may be attributed to the fact that the PSC TAC is not as binding on the Pacific cod fisheries, relatively speaking, than in the yellowfin sole and other flatfish fisheries.

Within the yellowfin sole and other flatfish fisheries larger reductions in the degree of bycatch aversion occur in the “other” flatfish fishery. These reductions are due to a high degree of heterogeneity present as a fair number of fishermen gravitate toward those regions which possess high bycatch. This suggests the fishermen within the flatfish fishery may be utilizing the bycatch information to enhance their production of flatfish later in the season, presumably because the flatfish and halibut are complements in production. Alternatively, given that the flatfish fishery season is shorter than in the Pacific cod and yellowfin sole fisheries, the peer pressure coercive forces in the yellowfin sole fishery may be stronger than in the flatfish fishery because they have more time to process and utilize the weekly vessel bycatch reports provided by NMFS.

Furthermore, our empirical results indicate that fishermen in both fisheries are more responsive to spatial bycatch rates than quantities. This directly corresponds with the information provided by Sea State and suggests that the provision of bycatch quantity information may help to further enhance cooperation within these fisheries. However, it is important to note that we are unable to completely decompose the effect of both pieces of information because we do not observe a control group for which rates information is not reported. In addition, other empirical results we have generated (see our manuscript) indicate that changes in bycatch rates and quantities have a more profound affect on fishermen behavior when they occur in locations which possess the highest rates/quantities of bycatch within the fishery. This further highlights the importance of bycatch information within these fisheries. Finally, our results indicate that a high degree of fisherman heterogeneity exists in both the yellowfin sole and flatfish fisheries which for the most part increases as the remaining bycatch TAC decreases, illustrating the breakdown of cooperative behavior in the fishery. This finding is consistent with the concerns outlined by Gauvin et al. (1995) in their initial investigations of the applicability and feasibility of the Sea State program.

This analysis generally supports the hypothesis that Sea State has been successful at helping fishermen within the yellowfin sole and other flatfish fisheries avoid bycatch, but has not had as profound of an effect on the Pacific cod trawl fisheries. However, there does appear to be a substantial opportunity to increase economic efficiency in these fisheries because perfect cooperation is not observed and there is a direct management conflict between the groundfish and halibut fisheries. Perhaps with the recent proposed rationalization of this fishery under Amendment 80 of the Bering Sea Fishery Management Plan management it will progress toward reducing this economic inefficiency. However, complete efficiency is unlikely to be obtained unless fishermen participating in the flatfish fisheries are allowed to own halibut quota and visa versa, as the common pool nature of the PSC TAC will still remain if the groundfish fisheries are rationalized but still operating under a PSC TAC for halibut. In such a system, economic efficiency still rests on the degree of fleet cooperation and not direct market mechanisms. This may prove to be a fruitful area of research in the future and one which we intend to pursue.

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