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Analysis

Bycatch risk pools for the US West Coast Groundfish Fishery

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Individual transferable quotas (ITQs) in multispecies fisheries create incentives for fishermen to avoid bycatch of species for which quota is scarce. However, when bycatch is highly uncertain, individual quota demand and prices may be volatile creating substantial financial risk for fishermen. The US Pacific Groundfish fishery recently introduced an ITQ system with low quotas for several overfished species with highly uncertain bycatch rates. Some fishery participants formed risk pools where bycatch quota is pooled and available to all pool members. Risk pools can reduce financial risk and transactions costs for individuals, but they also create moral hazard and adverse selection problems. We present an empirical analysis of bycatch risk that informs several issues of risk pool design including which bycatch species to include, pools size, and how to evaluate and mitigate adverse selection and moral hazard problems.

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1. Introduction

Economic analysis of the bycatch problem to date has mostly treated bycatch as a joint production problem where bycatch rates are either assumed to be fixed or can be reduced through behavioral changes that reduce target species catch rates and thereby increase cost per unit of catch (Arnason, 1994; Abbott and Wilen, 2009; Boyce, 1996; Singh and Weninger, 2009). These analyses show that individual transferable quotas (ITQ) or taxes can create incentives for fishermen to cost-effectively avoid bycatch of species for which quota is scarce. This allows greater harvest of target species without exceeding total allowable catches of weak stocks with low quotas which are taken primarily as bycatch.[1] These analyses have mostly utilized a deterministic framework and focused on the incentives required to induce fishermen to adjust behavior to achieve the desired bycatch rate. A few papers have explored the ramifications of stochastic bycatch (e.g., Androkovich and Stollery, 1994; Herrera, 2005; Segerson, 2007), but their focus has been on comparing the overall efficiency of alternative regulatory mechanisms such as taxes vs. quotas rather than exploring how uncertainty affects the efficiency and operation of a quota market and the financial risk for fishermen associated with uncertain costs of quota acquisition to cover bycatch.

For species with very small quotas and low average, but highly uncertain and variable bycatch rates, efficient quota markets could be subject to high price variability and might fail to allocate quota efficiently (Holland, 2010). For such species, the realized distribution of bycatch for individual fishermen is likely to be lumpy and disparate from quota holdings even if those holdings reflect the product of average bycatch rates and target species quota holdings. Quota ownership may also be quite dispersed, so a quota purchase to cover a large bycatch event may require a fisherman to purchase small amounts of quota from a large number of fishermen who each hold only small amounts of quota. This may lead to high transactions costs. Fishermen may hoard quota they ultimately would not need forcing other fishermen to stop fishing for lack of quota to cover bycatch. Even when quota markets operate efficiently they could leave individual fishermen facing high levels of income risk associated with costs of acquiring bycatch quota because efficient quota prices may be very high when the ratio of bycatch quota to target species quota is very small (Holland, 2010).

Risk pools, in which fishermen pool their bycatch quota and make it available free or at a nominal cost to other pool members, offer a

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[1] We use the term bycatch here to mean unintended or unwanted incidental catch but not necessarily catch that is unmarketable or discarded. Most of the species we focus on here are in fact marketable and may be retained for sale when caught but they are presumably not targeted but taken incidentally. Fishermen are by and large attempting to avoid catching them since total quotas are expected to constrain catch of other target species.

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means to mitigate financial risk and reduce transactions costs.[2] However, like any form of insurance, risk pools face problems with moral hazard and adverse selection[3] that must be addressed in formation and operation if they are to be effective. Risk pools have the potential to create moral hazard if avoiding bycatch increases the costs of fishing or reduces target species catch rates. An individual in a risk pool who can draw freely from the pooled quota at little or no cost will have less incentive to avoid bycatch. To mitigate moral hazard, risk pools may want to prescribe best practices for bycatch avoidance and/or make use of deductibles or co-insurance that create a financial incentive to avoid bycatch. Adverse selection may pose a problem for risk pools because individuals with higher bycatch risk or less quota to contribute are more likely to want to join risk pools then low risk individuals and individuals with more quota. Risk pools may want to evaluate relative risks of individuals and require greater initial contributions from those who pose more risk.

Although risk pools can reduce financial risk for members, by weakening individual incentives to avoid bycatch, risk pools may increase the risk that the aggregate bycatch of the pool members will exceed the pool's quota and require the pool to purchase additional quota or cease fishing. Thus there is a trade-off the risk pool must face when deciding whether or not to include a particular species (Table 1). For some bycatch species, where bycatch is frequent and variance in bycatch rates is low, risk pools might not provide substantial risk reduction because an individuals' total bycatch should be predictable over a large number of tows even if tow-by-tow bycatch is not. For these species an individual should be able to forecast his or her quota needs in advance and assemble an appropriate quota portfolio. It may be preferable to leave such species out of risk pools because including them provides little risk reduction but could undermine incentives to avoid bycatch. Risk pools also may be less desirable when the cost of avoiding bycatch is high, thereby increasing moral hazard. Risk pools may face greater adverse selection problems when bycatch rates between individuals are highly variable due to differences in fishing strategies or locations.

In 2011, an ITQ system was introduced for the limited entry trawl fleet in U.S. Pacific groundfish fishery. We refer to this hereafter as the LE trawl fishery. The ITQ system includes transferable quotas for a number of overfished rockfish species with very low total allowable catches (TACs) as well as individual bycatch quotas for Pacific halibut. Catch of some of these species is highly variable and many individuals were allocated very small quotas, insufficient in some cases to cover incidental catch from one unlucky “disaster” tow with much larger than average bycatch. Concern that it might be impossible or very costly to purchase additional quota in the event of exceeding one's own allocation led many fishery participants to consider forming risk pools.

Risk pools are meant to reduce financial risk for participants relative to reliance on a competitive quota market; however, their success may depend on how they are designed and operated, in particular how they address moral hazard and adverse selection problems. Holland (2010) noted these potential problems for risk pools but that analysis, based on a simplistic model that assumed bycatch risk was completely random, did not address either the severity of these problems or how risks could be mitigated by risk pool design. In this paper we present an empirical analysis of the relationship between bycatch risk and fishing behavior in the LE trawl fishery and discuss the implications of the results for design of risk pools. We present a non-parametric analysis of individual and pooled bycatch risk to illustrate which species are more or less suited to management with risk pools and how risks decline with risk pool size for different species. The non-parametric analysis also illustrates how expected bycatch and bycatch risk vary across regions creating potential adverse selection problems. We then estimate statistical models of expected bycatch that quantify how expected bycatch for different species is affected by fishing location, target species and other factors. This information could be used to design monitorable fishing practices that risk pools could specify to reduce moral hazard.

Table 1
Factors that affect the relative benefits of maintaining individual bycatch quotas vs. creating risk pools.

Favors maintaining individual quotas	Favors risk pools
Species caught frequently	Species only rarely caught
Low variance, normally distributed catch events	High variance, positively skewed catch events
High number of fishing events per vessel	Low number of fishing events per vessel
Bycatch risk correlated with expected profit	Bycatch risk uncorrelated with expected profit
Bycatch risk heterogeneous across vessels	Bycatch risk homogeneous across vessels
Real-time information sharing not useful for avoidance	Real-time information sharing useful for avoidance

2. Background on the fishery and initial risk pool development

In 2011, after several years of development, the Pacific Fishery Management Council implemented an ITQ system in the Pacific groundfish LE trawl fishery. Individuals were allocated quota shares for 28 groundfish stocks and stock complexes as well as individual bycatch quotas for Pacific halibut. Quotas for most species were allocated based on catch history, but, for seven overfished rockfish species and halibut, initial quota share allocations were based on bycatch rates applied to allocations of associated target species (Federal Register, 2010). We refer to quota for these species hereafter as bycatch quota to differentiate it from quota for target species though all except Pacific halibut can be landed and sold.

During the development of the ITQ program there was concern that the overfished rockfish species could be problematic because catch of some of these species is lumpy and unpredictable and it was expected to be very difficult for individuals to match catches to their quotas. Some of these species are encountered very rarely (Fig. 1) and, for some of the schooling rockfish species, there is a very small probability of very large catches in a single tow. Most individual fishers were allocated very small quantities of quota for some species and could easily exceed that quota with one unexpectedly large tow. Acquiring quota pounds[4] (QP) to cover an abnormally large tow could require purchasing the entire QP allocation of several other fishermen who might be reluctant to sell their quota knowing they might need it themselves later in the year. There was concern that individuals with unexpected high bycatch would find it difficult to acquire QP in the open market or might face exorbitant prices if they could find it (PFMC (Pacific Fishery Management Council) and NMFS (National Marine Fisheries Service), 2010).

Despite proposals to manage these bycatch species with other mechanisms (including auctions), quotas were allocated to individuals along with target species quotas, albeit with initial quota share based on bycatch rates for target species allocations rather than historical catch. As implementation of ITQ management approached, concern about the risk associated with bycatch of these species led some fishermen to explore formation of risk pools under which individual fishermen would collectively pool their QP of the bycatch species. Individuals

[2] Commitment to a reciprocal trading system with pre-contracted quota prices could also reduce risk and bargaining inefficiencies that arise from private information (Matouschekw and Ramezzanaz, 2007). Anecdotal accounts by fishermen in the British Columbian groundfish ITQ suggest that a reciprocal trading system, though informal, has operated for over a decade to distribute bycatch quota at nominal prices.

[3] Moral hazard can occur when an individual is insulated from risk and consequently has reduced incentives to avoid risk. Adverse selection occurs when an individual's demand for insurance (e.g. inclusion in the risk pool) is positively correlated with the individual's risk, and the insurer is unable to account for this correlation in the price of insurance.

[4] Quota pounds are the annual form of quota, denominated in pounds, which must be used to balance catches of ITQ species. Quota shares produce quota pounds for quota holders as a share of that year's total allowable catch.

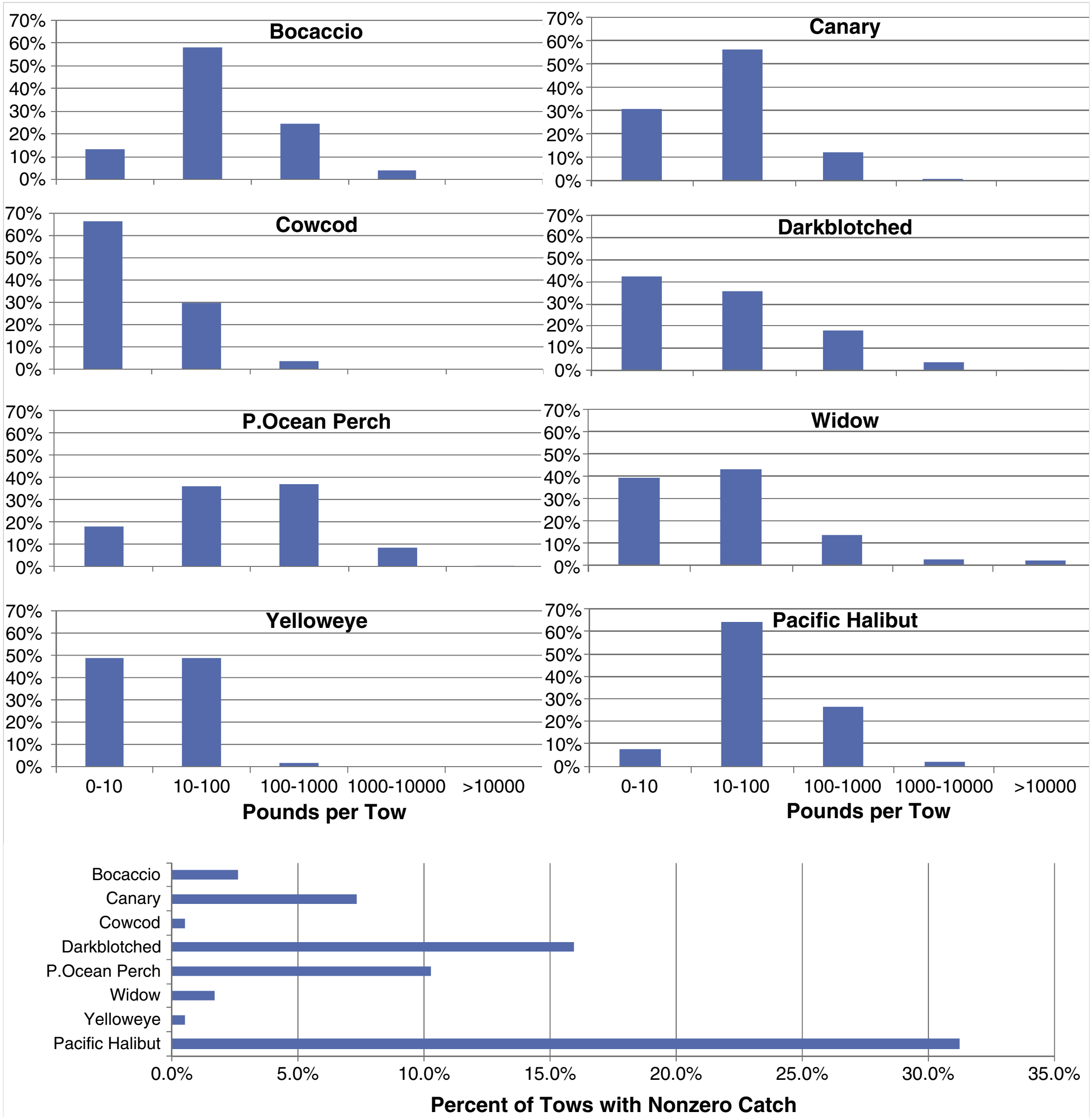

Fig. 1. Distribution of catch per tow for observed nonzero tows for 2002–2009 (note that the *x*-axes in the upper figure are a $\log_{10}$ scale).

would then be able extract QP from the pool to cover actual bycatch during the year. The motivation for these risk pools was primarily to mitigate the financial risk for individual fisherman associated with uncertainty over realized bycatch vs. their allocation and the availability and cost of acquiring QP to balance bycatch and avoid shutdown.[5] A second motivation for risk pools was to reduce the interdependent risk resulting from the fact that an individual who had not exceeded their own QP allocation could be shut down by a fishery closure if total bycatch of other fishermen exceeded the TAC. The rationale put forward was to bring everyone into risk pools even if they brought little or no constraining species QP to the pools or had a history of high bycatch. However, the perceived need to increase the size of risk pools to improve risk diversification and include individuals who appear to be bad risks to control interdependent risk clearly conflicts with the need to limit risk pool membership to control moral hazard and adverse selection.

Risk pools are based on private contracts and are not currently part of the regulatory framework. They have not been required to publicly disclose operational rules or membership, and consequently information on them is limited. However, one group of fishermen that was attempting to form a risk pool released a draft contract for the risk pool prior to the beginning of the 2011 fishing year (http://www.westcoasttrawlers.net/node/109). The proposed risk pool was to include members from three fishermen's associations: the Ilwaco Fishermen and Marketing Cooperative (IFMC) in Washington State, and the Fort Bragg Cooperative Groundfish Association (FBCGA) and the Central Coast Sustainable Groundfish Association (CCSGA) in California. The CCSGA includes a number of vessels, permits and quota owned by the Nature Conservancy.

The draft contract gave risk pool managers considerable control over individual fishing operations and the ability to monitor fishers by using data collected by on-board observers and in vessel logbooks. Under the draft contract, the members of these three associations would agree to adopt and enforce certain fishing rules for 2011 intended to reduce the risk of an unintentional harvest of the eight potentially constraining bycatch species and to pool some or all of their 2011 QP allocations for these species. QP would be pooled within each association but the other associations would agree to provide additional QP from their pools if another association ran out. Notably, risk pool members would be able to draw quota from the pool at no charge as long as they were following the rules. However, hired vessel

[5] This statement is based on observing discussions of industry members discussing formation and design of risk pools at a meeting held at the law office of Mundt and MacGregor L.L.P. on October 28, 2010.

captains as well as vessel owners are party to the risk pool contract and would face predefined penalties for not following risk pool rules. Technically these are pre-agreed remedies for liquidated damages because courts will generally not enforce “penalties” in civil contracts. The risk pool apparently failed to incorporate formally after the Ilwaco group decided not to join, however, the two Californian associations apparently began operating as if the contract were in force (personal communication Merrick Burden August, 2011).

Although this risk pool apparently did adopt this specific contract in 2011, it is instructive to examine its design and, in particular, how it addressed problems such as moral hazard and adverse selection. Each fishing association in the risk pool would prepare a fishing plan which must be approved by the risk pool board. Plans would specify member vessels' time, area, method and means of harvest of each target species and the proposed amounts and rates of associated incidental catch of constraining species. The fishing plans were to include rules that specified acceptable and unacceptable fishing practices including time and area closures, restrictions on gear and fishing depths and a requirement to retain and land all rockfish catch. If an association's vessels' aggregate catch of a constraining species were to rise above 75% of the annual projected catch for that species then the association would be required to amend the plan and specify the actions it would take to complete its annual fishery operations in compliance with its constraining species constraints.

The contract required risk pool members to transfer all of their QP for constraining species to holding accounts controlled by the risk pool board. A vessel's eligibility to have its bycatch covered by the risk pool would be determined on a trip-by-trip basis and subject to its compliance with the applicable regional rules. Bycatch amounts above threshold levels (e.g., as little as one fish for yelloweye rockfish but as high 1500 pound for darkblotched and widow rockfish) would trigger an audit to ensure the vessel was following regional rules. The captain of a vessel that had a haul exceeding prescribed per-tow catch thresholds would be required to notify other vessels harvesting in the same region within an hour. Risk pool managers (or their agent) would be given permission to access logbook and observer data to monitor and audit operations.

3. Materials and methods

The design of risk pools might be improved and made less *ad hoc* with more rigorous analysis of determinants and characteristics of bycatch of the overfished rockfish species in the trawl fishery over the past several years. Such an analysis could provide some useful insights into which species may be more or less suited for inclusion in risk pools, and on how bycatch risks vary with factors that might be capitalized on to address moral hazard and adverse selection issues. We conduct an analysis of bycatch using data collected by the West Coast Groundfish Observer Program (WCGOP) run by the Northwest Fisheries Science Center. These data account for approximately 20% of effort, and are the best source of data for analysis of bycatch. The LE groundfish trawl fleet submits logbook data with tow-by-tow catch estimates and locations for all tows for several years, but logbook data contains no information on discards. Most of the catch of the constraining rockfish species was discarded at sea; therefore, it is necessary to rely on the observer data for this analysis. As of 2011 the ITQ fishery has 100% observer coverage, so it will be possible to replicate this analysis in the future with complete data though that data may not be available until late 2012.

The WCGOP aggregates ports along the US west coast into port groups, which are considered sampling strata. Vessels with LE groundfish trawl permits were assigned to a port group based upon the location of the previous year's landings. Within each port group, the vessels were randomly selected for coverage during a 2-month period, which coincided with the 2-month cumulative trip limit period. After the entire fleet had been selected, a new selection cycle began. The observer data provide estimates of all catch, both retained and discarded, on a tow-by-tow basis along with ancillary information such as time and date, start and end locations for each tow, depth, etc.

Estimates of expected bycatch rates based on observer data could be biased if vessels fished differently with versus without an observer on board. The potential and extent of such bias is difficult to assess. However, the WCGOP annually reviews the spatial distribution of observed and unobserved vessels and this qualitative index does not suggest large differences in the spatial distribution of observed and unobserved vessels (Marlene Bellman, personal communication October 25, 2011). Because an observer was assigned to a vessel for a 2-month period coinciding with the bimonthly cumulative individual catch limits, the cost of making substantial changes in targeting behavior to avoid bycatch would be quite high for a vessel. In addition, the incentives for changing fishing behavior to avoid bycatch were not high because vessels could continue fishing and simply discard species for which they had already reached their bimonthly cumulative catch limits. For these reasons we believe the observer data should be representative of overall fishing behavior and associated bycatch rates for the pre-ITQ period.

It is less clear how well how well predictive models based on this data may reflect expected bycatch risk under the new ITQ regime with 100% observer coverage and full accountability for all catch. These data reflect the behavior of the vessels under the incentives of the old management system as well as the distribution of the bycatch species. During the period these data were collected, incentives to avoid bycatch were relatively weak. Individuals did have cumulative bimonthly catch caps for many species but they could continue fishing and discarding species for which they had reached the cap. However, the bimonthly caps and time-area closures were adjusted to keep overall mortality on various species below target levels, so high bycatch could lead to more restrictive management. There was apparently peer pressure to avoid bycatch but it is not clear how it affected behavior. Under ITQs the incentives to reduce bycatch will presumably be stronger and thus expected bycatch rates could decline substantially even, within a stratum. In addition to avoiding depths and regions with higher expected bycatch risk, fishermen may alter gear and fishing methods.

However, fishermen participating in risk pools who can draw freely from a pool of quota for the bycatch species, may have weak incentives to avoid bycatch beyond complying with risk pools rules such as depth restrictions. In that case, predictive models based on the historical bycatch data may be useful, at least in determining how relative expected catch for risk pool participants will vary according to factors such the depth and latitude fished. Nevertheless, models based on this pre-ITQ data may overstate the expected bycatch risks if vessels are both willing and able to reduce bycatch rates through fishing choices not controlled for in the model. Our analysis is most useful for understanding the relative bycatch risk across species and space.

3.1. Non-parametric analysis of bycatch risk

The relative bycatch risk and potential risk reduction from risk pooling is likely to differ substantially across species and regions. We undertake a Monte Carlo analysis based on random draws from observed trawls (2002–2009) and present measures that might be used to inform decisions on which species should and should not be included in the risk pools and how risk pool size affects risk reduction. The analysis also quantifies how bycatch risk varies across regions which may be important in determining how much risk individuals from different regions bring to a risk pool.

The data used includes over 26,000 individual observed tows by the limited entry groundfish trawl fleet between 2002 and 2009. Eight strata are defined by latitudinal breaks that correspond with fishing out of major fishing ports on the West Coast (Fig. 2), and the observer data is segregated by strata. For each of these strata, we

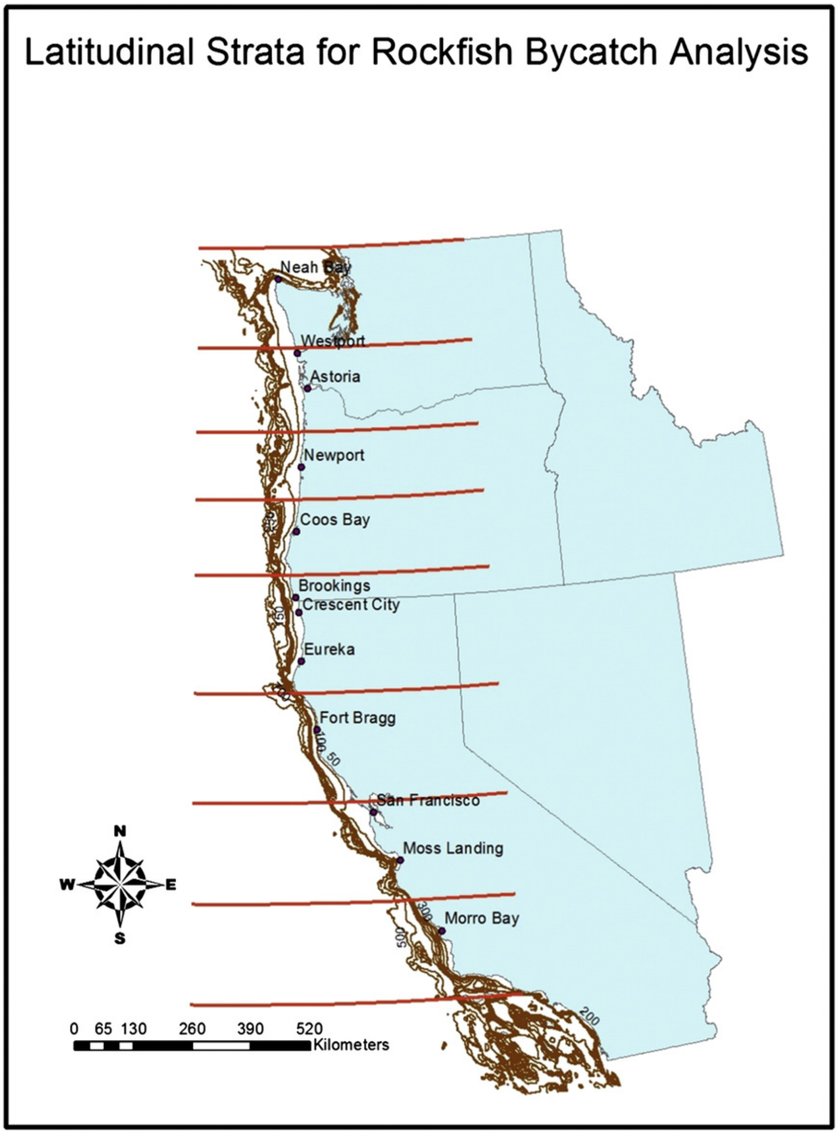

Fig. 2. Latitudinal strata used for analysis of bycatch in observer data.

randomly sample 100 tows (with replacement) and sum catch of constraining rockfish species and halibut for the 100 sampled tows. We replicate this sampling 1000 times to create a distribution of expected bycatch for a vessel fishing 100 tows in that strata. Although the actual number of tows varies across vessels, 100 tows is roughly the average number of annual tows limited entry groundfish trawl vessels fished in the groundfish fishery in 2010 and serves as a useful metric of expected bycatch for a vessel over the fishing year. The distribution of summed catch from 100 randomly sampled tows quantifies the residual uncertainty in bycatch risk, for fishing in a given strata, that is not averaged out over the year for an active vessel. While actual tow lengths vary, a statistical analysis of expected bycatch rates (below) shows little or no correlation between tow length and catch for most of the constraining rockfish species suggesting that using tows as the unit of effort is reasonable.

As Fig. 1 illustrates the distribution of bycatch for individual tows varies substantially across species. For all of these species, the great majority of tows have zero bycatch of a given species, and the distribution of positive tows is highly skewed to the right. For a few species (e.g., cowcod and yelloweye) bycatch is encountered on less than 0.5% of tows though the probability varies substantially by location as we discuss below. For a few of the rockfish species very large tows occur on very rare occasions. For example, widow rockfish has a small number of observed tows over 10,000 pounds. Aggregating catch for random samples of 100 tows from each strata considerably reduces the variance and skewedness of these expected catch distributions, but, for some of these species even the distribution of aggregate catch from 100 tows is highly variable and skewed leaving an individual facing a high degree of uncertainty in their potential annual QP requirements.

The desirability of including a particular species in a risk pool would be partly a function of the risk associated with the cost of acquiring QP for unexpected bycatch—a combination of price and transactions costs. Concern about being able to acquire QP at all is also a motivating factor, because a fisherman would be forced to stop fishing if they are in quota deficit and fishermen may be reluctant to sell quota they think they might need themselves later in the year. There are a number measures of risk that might be used to evaluate risk including the variance and skewedness[6] of the expected catch distribution. One useful metric used to evaluate risk that has become popular with insurance actuaries in recent years (Landman and Valdez, 2005)

[6] Highly skewed distribution tend to increase the downside risk. If individuals are downside risk averse (see Kimball, 1990 for a discussion of this) then it is more likely that quota markets will not function efficiently (Holland, 2010) and there may also be greater demand for insurance in the form of risk pools.

is tail conditional expectation (TCE) which is simply the expected value of the loss associated with some percentile of the distribution taken from the right tail (e.g. the 95th percentile loss). TCE has been shown to be a "coherent" risk measure satisfying a number of desirable axioms (Artzner et al., 1999). We use a variant on that metric here based on the mean of the 95th percentile right hand tail of the distribution of total catch for 100 randomly drawn tows. This TCE measure, denominated in pounds, is then compared to median catch (from 100 tows) and to median quota holdings. Generally a TCE would be quantified in terms of an expected value of loss to give a financial risk measure. However, the actual value of the loss associated with acquiring QP to cover bycatch is dependent on the price of QP which would depend, among other things, on realized fleetwide catch relative to total QP available and might be expected to vary greatly during the year (Holland, 2010). Nevertheless a TCE measure denominated in pounds provides an indicator of risk for the individual. Comparing it with median catch expectations gives an idea of the QP acquisition risk relative to the QP most individuals would expect to need.

3.2. Modeling expected bycatch rates

Expected bycatch rates are likely to depend not only on the region where an individual is fishing but on what they are targeting, the depths they are fishing in (which are closely related to targets), and whether the bycatch species was encountered the previous tow. An understanding of the factors that affect expected bycatch could be used to reduce moral hazard by specifying monitorable "best fishing practices" designed to reduce bycatch risk. For example these practices might include avoiding areas or depths with high expected bycatch rates and moving a specific distance away after encountering bycatch. Quantifying expected bycatch may also be useful in predicting a risk pool's overall quota needs contingent on a fishing plan.

We use the observer data described above to estimate expected bycatch rates using a delta (or hurdle) modeling approach combining a binary logit model for presence/absence of bycatch with a regression model of expected catch for positive tows.[7]

The probability of encounter bycatch for species j is:

$$P\left(\text{Catch}_j > 0\right) = \frac{\exp\left(\beta_j x_j\right)}{1 + \exp\left(\beta_j x_j\right)} \tag{1}$$

The expected catch (pounds) of species j conditional on catch for that species being positive is modeled as a log-linear regression reflecting the fact that catch per tow for positive tows is roughly log-normally distributed:

$$\ln\left(\text{Catch}_j \middle| \text{Catch}_j > 0\right) = \alpha_j x_j + \varepsilon_j \tag{2}$$

Because the dependent variable in the regressions is the log of catch, the exponentiated prediction $\exp(\alpha_j x_j)$ is biased. An unbiased estimate of expected conditional catch is:

$$E\left(\text{Catch}_j \middle| \text{Catch}_j > 0\right) = \exp(\alpha_j x_j)^* \exp\left(\sigma^2/2\right) \tag{3}$$

The unconditional expected bycatch for a given fishing tow is then calculated as the product of the logit probability that catch is positive and the conditional expected catch for positive tows:

$$E\left(\text{Catch}_j\right) = P\left(\text{Catch}_j > 0\right)^* E\left(\text{Catch}_j \middle| \text{Catch}_j > 0\right) \tag{4}$$

We model expected catch (both the probability of a positive tow and the expected catch for positive tows) as a function of a number of characteristics of the area fished and of the vessel and its recent fishing history. Because we do not necessarily expect a linear or even monotonic relationship between expected catch and depth or latitude, we use dummy variables for the same latitudinal strata used in the non-parametric analysis (Fig. 2) and we also create dummy variable for 50 fathom depth intervals. We also use dummy variables for target species, for year and quarter, and for whether the tow occurred at night. We include the length of the vessel and the length of the tow in the models. We also include the value of the species retained on the tow exclusive of the catch of the bycatch species that is the dependent variable. A positive and significant sign on this variable may be indicative of a greater opportunity cost associated with reducing expected bycatch and thus greater moral hazard. Finally we include a spatially constrained lagged dependent variable. The lagged dependent variables in these models are constructed as a product of the lagged dependent variable (either a binary variable indicating whether the species was caught the previous tow for the logit models or the log of pounds of bycatch the previous tow for the regressions of expected catch) and a dummy variable that is positive only if the prior tow was on the same trip and the endpoint of the prior tow was within a specified distance of the starting point of the observed tow.

4. Results

4.1. Non-parametric analysis

Absolute TCE, the ratio of TCE to median catch for 100 tows, and ratio of TCE to median quota holdings are shown in Table 2. Several species-strata have TCE over 10,000 pounds but it may be more meaningful to look at the ratio of the TCE to the median catch. For example, while the TCE for Pacific halibut in the strata north of 47 degrees is over 22,000 pounds, it is only about twice the median catch. In contrast, the TCE for widow rockfish between 42° 10′and 42° 30′ is a little over 19,000 pounds which is 2500 times the median catch of 8 pounds. Some species such as cowcod and yelloweye, which have a low absolute TCE, also have very low median catch rates and very low overall TACs. If they became constraining the cost of QP for those species might become quite high as the shadow value of the QP would be high reflecting a very small ratio of bycatch to target catch. It is not clear what specific absolute level of TCE or ratio relative to median catch would be considered a sufficient risk to validate inclusion in a risk pool. However, Pacific halibut would appear to be one of the lowest priorities for pooling while widow rockfish might be highest.[8]

The ratio of the TCE to median quota holdings in Table 2 provides another indicator of risk as well as potential transactions costs. When TCE is many times median quota holdings, individuals that end up with high catches are not only more likely to have to acquire additional quota, they may have to acquire quota from a number of different individual, thereby increasing transactions costs. TCE for several species and regions is more than 20 times median quota holdings. For example, for yelloweye rockfish the median quota holdings are only 2 pounds and average quota holdings are 5 pounds. Though the TCE for yelloweye rockfish is low in absolute terms, in some regions it is as high as 106 times the median quota holdings. Even if quota prices rise to high levels and the total cost of purchasing quota is therefore not high, an individual may have to go to many other individuals to piece together enough quota and would have to cease fishing for some time while acquiring the quota to cover an overage. For widow rockfish, in contrast, the ratio of TCE to median quota holdings gives a somewhat more optimistic picture of risk than the ratio of TCE to median catch. Although the

[7] As we discuss at the end of the results section we attempted estimating models with zero inflated count models but found they either failed to converge or predict well.

[8] Holland (2010) showed in a theoretical analysis of bycatch modeled as a random Bernoulli process that the benefits of risk pooling as well as the size of risk pool increase as the probability of bycatch occurring declines.

Table 2
a) 95th percentile tail conditional expectation (TCE) of bycatch, b) median pounds of bycatch, (c) median allocations of quota pounds in 2011 for all quota share owners, (d) the ratio of TCE to median catch by species and latitudinal strata and (e) the ratio of TCE by species and latitudinal strata to median quota pounds allocations for all quota share owners.

	Bocaccio	Canary	Cowcod	Darkblotched	Pacific Ocean perch	Widow	Yelloweye	Pacific halibut
(a)	95th Percentile TCE							
North of 47'	n.a.	3627	n.a.	8,398	24,537	11,444	212	22,574
45′20″ to 47′	n.a.	1148	n.a.	7,339	23,026	28,279	52	3,575
44′ to 45′20″	n.a.	1413	n.a.	8,133	6,773	400	74	14,841
42′30″ to 44	n.a.	2502	n.a.	16,911	2,794	240	91	5,254
40′10″ to 42′30″	n.a.	7504	n.a.	11,645	1,056	19,274	11	3,566
38′ to 40′10″	4081	326	251	7,159	n.a.	2,138	55	n.a.
36′ to 38′	8787	1150	242	2,244	n.a.	4,386	33	n.a.
South of 36'	763	9	166	896	n.a	15	–	n.a.
(b)	Median Catch							
North of 47′	n.a	1,101	n.a	1,969	9,225	22	18	12,428
45′20″ to 47'	n.a	150	n.a	1,890	4,643	48	-	2,052
44′ to 45′20″	n.a	576	n.a	735	580	24	4	9,278
42′30″ to 44	n.a	490	n.a	5,243	502	9	-	2,297
40′10″ to 42′30″	n.a	192	n.a	1,332	17	8	-	2,002
38′ to 40′10″	759	73	6	1,478	n.a	221	-	n.a
36′ to 38′	2,026	79	42	53	n.a	26	-	n.a
South of 36'	204	-	-	248	n.a	4	-	n.a
(c)	QP allocations (all quota share owners)							
Median nonzero QP	392	339	7	3,730	1,129	3,994	2	940
Avg. Nonzero QP	2,242	446	50	4,320	2,056	4,867	5	2,012
Owners with no QP	80	11	80	11	11	11	15	11
(d)	Ratio of 95th Percentile TCE to Median Catch							
North of 47'	n.a	3.3	n.a	4.3	2.7	520.2	12.1	1.8
45'20" to 47'	n.a	7.7	n.a	3.9	5.0	585.5	1.0	1.7
44' to 45'20"	n.a	2.5	n.a	11.1	11.7	16.4	18.6	1.6
42'30" to 44	n.a	5.1	n.a	3.2	5.6	26.1	1.0	2.3
40'10" to 42'30"	n.a	39.1	n.a	8.7	61.7	2,536.0	1.0	1.8
38' to 40'10"	5.4	4.5	44.9	4.8	n.a	9.7	1.0	n.a
36' to 38'	4.3	14.6	5.7	42.7	n.a	168.7	1.0	n.a
South of 36'	3.7	1.0	1.0	3.6	n.a	3.9	1.0	n.a
(e)	Ratio of 95th Percentile TCE / Median Nonzero QP Allocations							
North of 47'	n.a	10.7	n.a	2.3	21.7	2.9	106.0	24.0
45'20" to 47'	n.a	3.4	n.a	2.0	20.4	7.1	26.2	3.8
44' to 45'20"	n.a	4.2	n.a	2.2	6.0	0.1	37.1	15.8
42'30" to 44	n.a	7.4	n.a	4.5	2.5	0.1	45.4	5.6
40'10" to 42'30"	n.a	22.1	n.a	3.1	0.9	4.8	5.3	3.8
38' to 40'10"	10.4	1.0	35.9	1.9	n.a	0.5	27.6	n.a
36' to 38'	22.4	3.4	34.5	0.6	n.a	1.1	16.6	n.a
South of 36'	1.9	0.0	23.7	0.2	n.a	0.0	0	n.a

absolute TCE is high, the ratio of TCE to median quota holdings is relatively low because there is a fair amount of quota pounds allocated and it is relatively well dispersed.

We can also use TCE measures to evaluate how risk pools of various sizes would reduce uncertainty and variability in expected catch for pool members using distributions of aggregate catch from multiples of the 100 tow average for individual tows. Table 3 shows the TCE measures for a single vessel and pools of 10 and 50 vessels (e.g., for distributions of aggregate catch from random samples of 100, 1000 and 5000 tows). For comparative purposes the TCE measure shown in Table 3 is the TCE divided by the pool size so that the TCE is comparable across pool sizes. These measures reflect a pool member's expected exposure to bycatch risk if they are liable for an equal share of the pools bycatch. With the exception of halibut, a pool size of 10 reduces TCE by at least 40% and as much as 75% relative to the TCE for a single vessel fishing 100 tows. Increasing pool size to 50 reduces TCE further, but the additional reductions in TCE are relatively small compared to what is achieved by pooling just 10 vessels, ranging from 6% to 18% of the single vessel TCE. Because larger pool sizes are likely to increase moral hazard and adverse selection problems it may make sense to keep risk pools at the smallest size possible. Limiting pool size in itself can reduce moral hazard since individuals are more affected by the risk of their own actions.[9] This analysis does not provide definitive advice on which species to pool or what the pool size should be, rather, it can be used as a guide to inform pool developers when making decisions about risk pool design. It does suggest that it is probably not necessary to form large coast-wide risk pools to manage bycatch risk and that including all of the overfished rockfish species and halibut may not be desirable.

The analysis of bycatch risk above also has some bearing on who might participate in risk pools and on adverse selection issues. Clearly the bycatch risk varies substantially across strata and these strata roughly correspond with the fishing areas for the fleets fishing out of the primary ports (Table 3). Vessels fishing out of ports with low TCE might be reluctant to participate in risk pools with vessels out of high TCE ports unless those vessels were contributing correspondingly higher QP to the pool. Because quota shares for overfished rockfish species were allocated based on bycatch ratios relative to target species allocations, one might also expect that the aggregate quota holdings of individuals fishing in different areas would be somewhat proportionate to the expected average bycatch in these areas so that they would bring QP to the pool somewhat in proportion to the

[9] Lee and Ligon (2001) show that in the presence of moral hazard there are typically finite optimal pool sizes.

Table 3
95th Percentile tail conditional expectation (TCE) of pounds of bycatch by species and latitudinal strata for 100 share of a pool of 100, 1000 or 5000 tows (e.g. pools of 1, 10 or 50 vessels fishing 100 tows).

Species	Pool size	North of 47'	45'20" to 47'	44' to 45'20"	42'30" to 44	40'10" to 42'30"	38' to 40'10"	36' to 38'	South of 36'
Bocaccio	Pool = 1	n.a	n.a	n.a	n.a	n.a	4,081	8,787	763
	Pool = 10	n.a	n.a	n.a	n.a	n.a	1,944	3,948	394
	Pool = 50	n.a	n.a	n.a	n.a	n.a	1,476	3,058	315
Canary	Pool = 1	3627	1,148	1,413	2,502	7,504	326	1,150	9
	Pool = 10	1842	489	844	1,111	2,239	166	439	4
	Pool = 50	1524	336	723	862	1,345	130	298	3
Cowcod	Pool = 1	n.a	n.a	n.a	n.a	n.a	251	242	166
	Pool = 10	n.a	n.a	n.a	n.a	n.a	77	109	58
	Pool = 50	n.a	n.a	n.a	n.a	n.a	48	83	42
Darkblotched	Pool = 1	8398	7,339	8,133	16,911	11,645	7,159	2,244	896
	Pool = 10	3779	3,467	3,239	9,080	4,867	3,293	667	468
	Pool = 50	2899	2,799	2,170	7,471	3,344	2,510	362	378
P. Ocean Perch	Pool = 1	24,537	23,026	6,773	2,794	1,056	n.a	n.a	n.a
	Pool = 10	13,512	11,034	2,611	1,301	407	n.a	n.a	n.a
	Pool = 50	11,486	8,428	1,735	980	217	n.a	n.a	n.a
Widow	Pool = 1	11,444	28,279	400	240	19,274	2,138	4,386	15
	Pool = 10	3016	7,878	150	82	5,797	871	1,291	7
	Pool = 50	1501	4,276	102	52	3,051	601	767	5
Yelloweye	Pool = 1	212	52	74	91	11	55	33	-
	Pool = 10	81	17	28	32	3	17	11	-
	Pool = 50	57	10	19	22	2	10	7	-
Pacific Halibut	Pool = 1	22,574	3,575	14,841	5,254	3,566	n.a	n.a	n.a
	Pool = 10	15,406	2,531	11,099	3,154	2,471	n.a	n.a	n.a
	Pool = 50	14,149	2,298	10,178	2,787	2,232	n.a	n.a	n.a

bycatch risk they bring to the pool. However, even if their allocations match their expected average bycatch, the relative difference in risk of high bycatch (as measured by TCE or some other metric) is still likely to be proportionately much higher than relative differences in expected (average) bycatch which could increase the exposure to risk for some individuals coming from low risk areas. For this reason we might expect to see risk pools form geographically, including members who fish in the same area. Because the analysis above suggests that relatively small pools (10 vessels or less) can provide substantial risk reduction, we might expect to see relatively small, geographically homogeneous pools. Smaller risk pools nested in a larger reciprocal trading agreement amongst pools might reduce adverse selection problems while still providing some of the advantages of a large pool in terms of risk spreading lower transactions costs.

4.2. Expected bycatch analysis

The statistical probability of encountering a bycatch species, and conditional and unconditional expected catch are significantly affected by latitudinal strata and depth for all of the bycatch species (See Tables 4 and 5 for detailed results of the statistical models). Expected catch is also much higher if the species was caught on the previous tow in the same trip that started within a specified distance of the end of the prior tow. The distance used to construct the lagged dependent variables varies by species according to the distance that provided the best fit (highest likelihood): bocaccio—20 nautical miles (nm), canary —30 nm, cowcod—20 nm, darkblotched—40 nm, widow—25 nm, yelloweye—5 nm, and Pacific Halibut—40 nm. It is notable that the increase in bycatch risk associated with catch the prior tow remains much higher for several species even when the individual moved several miles. Bycatch of some species is influenced by the target species and by whether fishing is at night, but these effects vary by species (e.g. some have increased and some decreased expected catch for day or night fishing). Vessel length, which is a proxy for fishing power and net size, is significantly and positively related to expected catch for some but not all species, mainly effecting probability of encounter as opposed to the amount of catch. The length of the tow is not a significant predictor of bycatch probability or amount for most species, and, when it is significant, the effect on expected catch is weak. For several species expected catch is positively correlated with the value of the tow exclusive of the value coming from that species. This suggests that avoiding bycatch might be costly in terms of forgone catch of target species per unit of effort, confirming the likelihood that moral hazard may remain even after controlling for location strata and other variables.

Using these delta models to predict how expected catch per tow varies for different latitudinal-depth strata and how it is affected by moving after encountering bycatch is illustrative of the importance of location choice (at a relatively coarse and monitorable spatial scale) in determining bycatch of the constraining species. Fig. 3 shows predicted expected catch for three of the bycatch species that were of greatest concern to West Coast groundfish fishermen fishing under the new ITQ system—canary rockfish, darkblotched rockfish and yelloweye rockfish. The black columns in Fig. 3 show predicted average catch per tow for various latitudinal-depth strata holding other variables such as target species, annual, and quarter dummies constant at their average values for that strata. As Fig. 3 demonstrates, expected bycatch rates vary substantially by latitude and depth. For canary and yelloweye rockfish in most latitudes moving from the 100–150 fathom interval to the 150–200 fathom interval dramatically reduces expected catch. However that move increases expected catch for darkblotched rockfish. Expected catch for darkblotched tends to in peak in the 150–200 fathom depth interval. This type of information could be used to design fishing rules to reduce a risk pool's expected bycatch and control moral hazard.

Like the nonparametric analysis described above, the statistical models indicate that average catch rates for some species will vary substantially depending on the region one fishes as well as the depth. Expected catch rates for bocaccio and cowcod are higher in the South and close to zero further north, while expected catch of Pacific Ocean perch and Pacific halibut are higher in the North and very low in the South. Bocaccio and cowcod caught North of 40°10′ latitude are actually not counted against quota, and the same is true for Pacific halibut and Pacific Ocean perch caught south of that latitude. Nevertheless, regional heterogeneity in expected catch rates could make it difficult to form large coast-wide risk pools because risks are so heterogeneous across regions, but these models could be used to estimate the amounts of quota that individuals from disparate regions might be expected to contribute to the risk pool to offset their expected bycatch. Depth related patterns of expected catch rates for other species like canary and darkblotched rockfish are more homogeneous across regions but there are still substantial latitudinal differences in absolute expected catch rates.

Table 4
Regression coefficients (parentheses indicate negative values) and significance for presence/absence logit models for bycatch of overfished rockfish species based on observer data from 2002 to 2009 (1% significance is denoted with ** and 5% significance with*).

Variable	Bocaccio	Canary	Cowcod	Darkblotch	POP	Widow	Yelloweye	Halibut
Nonzero Bycatch t-1	1.80 **	1.79 **	1.39 **	1.97 **	1.77 **	2.38 **	1.93 **	1.38 **
Year-02	(5.62) **	(2.49) **	(9.76) **	(3.59) **	(5.88) **	(5.03) **	(7.80) **	(1.41) **
Year-03	(6.80) **	(2.57) **	(12.24) **	(3.69) **	(6.39) **	(6.53) **	(8.59) **	(1.91) **
Year-04	(6.72) **	(3.14) **	(11.48) **	(4.29) **	(6.40) **	(6.15) **	(8.71) **	(1.68) **
Year-05	(5.99) **	(3.07) **	(10.89) **	(4.28) **	(6.66) **	(6.28) **	(8.36) **	(1.37) **
Year-06	(6.60) **	(2.99) **	(11.25) **	(3.85) **	(6.49) **	(6.50) **	(8.53) **	(1.33) **
Year-07	(6.79) **	(3.03) **	(12.15) **	(3.58) **	(6.31) **	(5.52) **	(10.84) **	(1.22) **
Year-08	(6.65) **	(3.22) **	(12.79) **	(3.70) **	(6.27) **	(5.75) **	(8.88) **	(1.20) **
Year-09	(6.15) **	(3.17) **	(11.73) **	(3.53) **	(6.11) **	(5.39) **	(9.69) **	(1.14) **
Qtr-1	–	0.33 **	(2.15) **	–	–	0.81**	–	0.24 **
Qtr-2	–	–	(0.39)	(0.35) **	(0.24) **	–	(0.54) **	0.12 *
Qtr-3	–	–	–	(0.18) **	0.13	–	–**	(0.15) **
Qtr-4	–	–	(0.96) **	(0.23) **	–	–	–	–
Night	–**	0.14 *	–	–	(0.16) **	(0.61) **	–	0.18 **
Vessel Length	(0.001)	0.002 *	–	–	–	0.01 *	0.036 ##	0.002 **
Haul Value	0.0001 **	0.0001 **	–	0.000 **	0.0001 **	0.00 *	–	0.000 **
Targ–DTS complex	-	(0.64) **	–	–	–	(1.04) **	(0.51)	(0.50) **
Targ–NSM complex	(0.37) **	(0.42) **	–	–	(0.35) **	(0.99) **	(0.90) **	–
Targ–Petrale	–	(0.41) **	–	–	0.59 **	(0.28)	(0.74) **	0.65 **
Targ–Dover	(0.94) **	(0.59) **	–	0.34 **	0.22 **	(1.01) **	(1.41) **	–
Targ–CA Halibut	-	(1.27) **	–	–	–	–	–	–
Targ–Sablefish	–	–	–	0.20	0.52 **	–	–	(0.86) **
Targ–Thornyheads	–	–	–	(1.37) *	–	–	–	(2.42) **
Targ–Sanddab	(0.97) **	(1.08) **	-	(0.53) *	–	(2.41) *	–	–
Targ–Longspine Thornheads	–	–	–	–	–	–	–	–
Targ–Arrowtooth	–	–	–	–	–	–	–	–
Targ–English Sole	0.95*	–	–	–	–	–	–	–
Targ–Sand Sole	–	–	–	–	–	–	–	–
0–50 fm	–	–	–	–	–	–	1.94	–
50–100 fm	3.22 **	1.68 **	5.31 **	2.30 **	(0.04)	1.70 **	2.92 **	0.58 **
100–150 fm	4.00 **	1.31 **	6.14 **	3.67 **	3.62 **	3.04 **	2.25 *	0.19
150–200 fm	2.73 **	(0.85) **	5.13 **	3.81 **	4.02 **	2.42 **	1.76	0.69 **
200–250 fm	1.50 **	(1.20) **	2.42 *	2.80 **	3.32 **	1.79 **	0.39	0.58 **
250–300 fm	–	–	–	1.52 **	–	–	(2.13)	(0.14) *
>250 fm	(3.07) **	(3.36) **			2.05 **	(0.79) *		
>300 fm			-	(0.46) **				(2.16) **
S. of 36 D	1.17 **	(2.22) *	-	(1.46) **	(2.72) **	(1.40) *	–	(4.49) **
36 to 38 D	2.32 **	(0.71) **	4.52 **	(1.34) **	(3.97) **	0.01	(1.70) **	(3.26) **
38 to 40–10 D	1.96 **	(0.02)	3.33 **	(0.87) **	(0.92) **	0.63 **	0.16	(1.68) **
40–10 to 42–30 D	–	–	–	–	–	(0.11)	(1.56) *	(0.30) **
42–30 to 44 D	(1.27) **	0.29 *	-	0.26 **	1.00 **	(0.43) *	-	(0.48) **
44 to 45–20 D	(1.94) **	(0.37) **	–	0.15	1.55 **	0.43 *	(0.36)	-
45–20 to 47 D	(2.22) **	(0.56) **	–	0.20 **	2.23 **	0.32 *	(0.53)	(0.16) **
N. of 47 D	0.03	0.35 **	–	(0.02)	2.98 **	–	0.29	0.93 **
Tow duration	–	–	–	–	–	–	0.12 **	-

The models also provide some information on how the risk pools might structure dynamic rules that respond to real time information about bycatch events. As Fig. 3 illustrates, the expected bycatch is much higher if the individual encountered that species on the previous tow and continued to fish in the same areas. The grey columns in Fig. 3 show expected catch when the lagged dependent variable is zero (e.g. that species was not encountered the previous tow or the vessel moved a substantial distance) in comparison to predictions when the lagged dependent variable is set at the average levels in the observer data (black columns). For canary rockfish expected catch increases by as much as 140% if it was encountered on the prior tow relative to predictions with historical average behavior. The effect of catch the previous tow varies by species. It has relatively little impact on expected catch for yelloweye rockfish, but this may reflect the extreme rarity of encountering yelloweye. There are very few positive tows in the observer data and extremely few consecutive positive tows on the same trip. Although these models looked at how expected catch for a particular individual was related to their own bycatch the prior tow, the bycatch of others would presumably be affected as well. Sharing of information on bycatch and requiring all vessels to move from areas where bycatch had occurred would thus appear to be an effective means of reducing bycatch though it is likely a costly measure as well.

These models could also be used to evaluate whether an individual's or an association's proposed target catch plan is in balance with its projected constraining species QP requirements. As the year progresses, it is likely that the catch of the most constraining species will change relative to initial expectations and these models could help guide in-seasons amendments to fishing plans that reduce the likelihood of running up against QP constraints of which ever species proves to be most constraining.

The predictive power of the expected catch models varies considerably across species. Comparisons of expected catch form the lognormal delta models with actual mean catch rates by latitude and depth strata suggest that, for some species, the models predict quite well. However, the models have poor predictive power for others species which have high average catches in a few latitude-depth strata, most notably widow rockfish (see Figs. 4–7). While the predictive ability of the model may not be fairly judged by comparing these predictions with mean catches (because those mean catches may be influenced by outliers in small samples), the comparisons do suggest the models have a hard time predicting the highest expected bycatch rates, particularly for species that have very large but rare bycatch events . This may suggest much greater uncertainty and ambiguity in predictions for these species, but alternative statistical models may also be called for.

Table 5
Regression Coefficients (parentheses indicate negative values) and Significance for Models of Log of Catch of Overfished Rockfish Species for Tows with Positive Catch of That Species Based on Observer Data from 2002–2009. (1% significance is denoted with ** and 5% significance with *).

Variable	Bocaccio	Canary	Cowcod	Darkblotch	POP	Widow	Yelloweye	Halibut
Log Bycatch t-1	0.08 **	0.12 **	–	0.21 **	0.08 **	0.21 **	0.22 *	0.15 **
Year-02	1.80 **	2.56 **	0.91 **	2.38 **	2.57 **	2.77 **	–	2.90 **
Year-03	1.47 **	2.80 **		2.39 **	2.72 **	2.88 **	–	2.85 **
Year-04	1.33 **	2.61 **	1.26 **	1.78 **	2.42 **	3.06 **	–	2.77 **
Year-05	1.63 **	2.62 **	–	1.99 **	2.07 **	2.53 **	–	3.05 **
Year-06	1.72 **	2.39 **	–	2.20 **	2.45 **	2.84 **	–	2.91 **
Year-07	1.40 **	2.56 **	0.93 *	2.14 **	2.26 **	3.14 **	–	2.98 **
Year-08	1.34 **	2.33 **	1.22 *	2.09 **	2.08 **	2.96 **	–	2.79 **
Year-09	1.34 **	2.39 **	–	2.24 **	2.22 **	3.20 **	–	3.03 **
Qtr-1	(0.76) **	–	–		–	(0.44) *	–	–
Qtr-2	–	–	–	(0.26) **	–	–	–	–
Qtr-3	–	–	–	(0.16) *	–	–	–	0.06 *
Qtr-4	–	0.31 **	–		–	–	–	–
Night	–	–	–	(0.14) *	(0.30) **	-	-	–
vessel length	–	–	–	–	–	–	0.03 *	0.002 **
haul value	0.0002**	–	–	0.00**	0.0002**	0.00004	–	0.0001 **
Targ–DTS complex	–	–	–	(0.45)**	(0.57)**	(1.26) **	–	–
Targ–NSM complex	–	(0.22)**	–	(0.28) **	(0.58) **	(1.09) **	–	–
Targ–Petrale	–	(0.30)**	–	(0.40) **	(0.83) **	(1.14)**	–	–
Targ–Dover	–	(0.31) *	–	(0.47)**	(0.68)**	(1.36)**	1.93**	–
Targ–CA Halibut	–	(1.38) **	–	–	–	–	–	–
Targ–Sablefish	–	–	–	–	–	–	–	(0.34) **
Targ–Thornyheads	–	–	–	–	–	–	–	–
Targ–Sanddab	–	(0.86)**	–	(1.16)**	–	–	–	0.35 **
Targ–Longspine	–	–	–	–	–	–	–	–
Targ–Arrowtooth	–	–	–	–	–	–	–	–
Targ–English Sole	–	–	–	–	–	–	–	–
Targ–Sand Sole	–	–	–	–	–	–	–	–
0-–50 fm	–	–	–	–	–	–	0.48	–
50–100 fm	(0.01)	0.58 **	0.65	(0.46) **	(0.57) **	1.13 **	0.73	0.25 **
100–150 fm	1.05 **	0.69 **	2.04 **	1.07 **	1.77 **	1.35 **	0.86	0.29 *
150–200 fm	0.78 **	0.39	1.82 **	1.72 **	1.57 **	1.50 **	1.04	0.46 **
200–250 fm	0.01	(0.33)	–	1.17 **	1.19 **	1.21 **	(0.02)	0.46 **
250–300 fm	–	–	–	0.41 *	-	-	(1.50)	0.36 **
>250 fm	0.87	(0.49)			0.49 **	0.80	-	
>300 fm	–	–	–	(0.01)	-	-	-	(0.04)
S. of 36 D	1.69 **	(1.16)	0.33	(0.93) *	0.48	(2.16) *	-	(1.36)
36 to 38 D	2.05 **	(0.28)	0.60	(1.07)	(3.23) *	0.30	(0.34)	(0.25)
38 to 40-10 D	1.77 **	(0.28)	–	0.04	(0.57)	(0.07)	(0.01)	(0.37) **
40–10 to 42–30 D	-	0.04	–	–	(0.89) **	0.64	1.16	(0.04)
42–30 to 44 D	0.76	0.22 *	–	0.14	–	(0.02)	–	(0.20) **
44 to 45–20 D	0.93	(0.21)	–	0.33 **	0.84 **	(0.22)	(0.41)	–
45-20 to 47 D	0.37	(0.32) **	–	0.20 *	1.66 **	0.57 *	(0.33)	(0.24) **
N. of 47 D	1.68 **		–	0.31	1.84 **	-	(0.03)	0.44 **
haul duration	–	–	–	–	(0.05) **	(0.11) *	–	0.01 *
Variance residuals	1.87	1.5237	1.53	2.92	2.75	2.63	1.40	1.20

It would theoretically be theoretically desirable to estimate catch probability and expected catch size jointly using a zero inflated Poisson or negative binomial count model and we did attempt this. However, those model specifications generally failed to converge, and for the few models that did converge, the estimates of expected catch appear to underestimate expected bycatch in peak areas (at least in comparison to the lognormal delta models and to actual mean catch per tow to some latitudinal-depth strata). The zero inflated models are meant to address the fact that zero tows may occur for two different reasons: (1) because the tow occurred in an areas devoid of that species of fish in the area, or (2) because the tow simply missed the fish that were there. However, neither the binomial nor Poisson distributions seem to fit the positive tow data as well as lognormal model. This may be due to positive tows actually being drawn from different distributions. Thorson et al., 2011 hypothesize that for some of these rockfish species which form large shoals, positive catches that encounter a shoal of fish can be associated with a different distribution than catches that encounter the species when it is more dispersed. They explore the use of mixed distribution models that estimates the probability of zero tows, an encounter with a collection of solitary individuals, or an encounter with a shoal of fish. This analysis was applied to survey data but the modeling technique might be usefully applied to the fishery dependent data as well.

5. Discussion

Risk pools may be a useful management tool for fisheries with hard TACs on species for which catch is rare and highly variable. When implemented to cover bycatch of constraining species in ITQ systems, they offer a means to reduce financial risk for fishermen and might also reduce transactions costs associated with getting quota to those that need it. This analysis suggests that rules specifying fishing depths and latitudinal zones and requirements to move after a bycatch event could be effective at reducing bycatch risk. They would also be easily enforceable in this fishery since there is 100% observer coverage. Risk pools that operated in 2011 did in fact use depth restrictions to limit where members could fish though based on a more subjective assessment.

Preliminary data on actual catch is now available for the first year of the ITQ program.[10] Catch of the seven overfished rockfish species

[10] This data is may not include catches at the end of the year and some catches that were discarded. Accurate catch estimates by vessels and in total will not be available until observer sampling data on discards is processed which may not be until late in 2012.

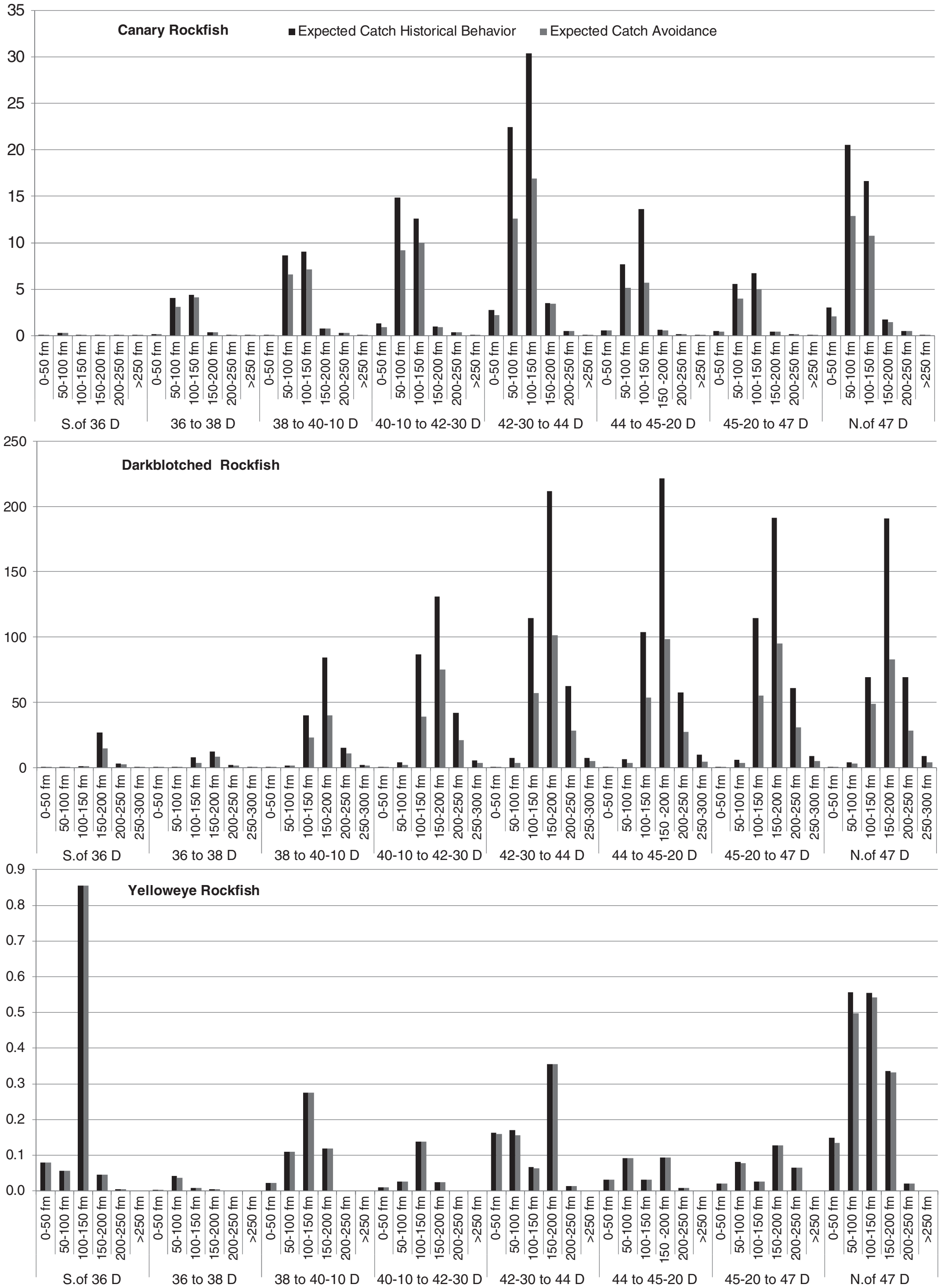

Fig. 3. Predicted catch per tow by latitudinal and depth strata for canary rockfish, darkblotched rockfish and yelloweye rockfish with historical behavior and avoidance (moving after an encountering bycatch). Predicted catch of yelloweye rockfish south of 36 degrees latitude is unrealistic and is due a zero parameter for that latitude.

in 2011 turned out to be much lower than expected. Though a few fishermen exceeded their allocations and had to acquire more quota, there was a large aggregate surplus of quota for all species. This includes the target species as well as the overfished rockfish species, particularly the species found primarily in shallower waters. Fishermen apparently largely avoided areas of high bycatch risk and concentrated on target species in deeper water where bycatch risk was lower. This suggests highly risk-averse behavior which may have been due to fears about being able to acquire quota to cover bycatch. Presumably a much higher proportion of target species quotas could be taken without exhausting bycatch species quotas; however, the bycatch of the overfished rockfish species is unlikely to correspond closely to quota allocations requiring substantial redistribution of quota through markets or risk pools. Bycatch is likely to be concentrated by a relatively small number of vessels and the distribution may not correlate well with quota allocations. As Table 6 shows, for

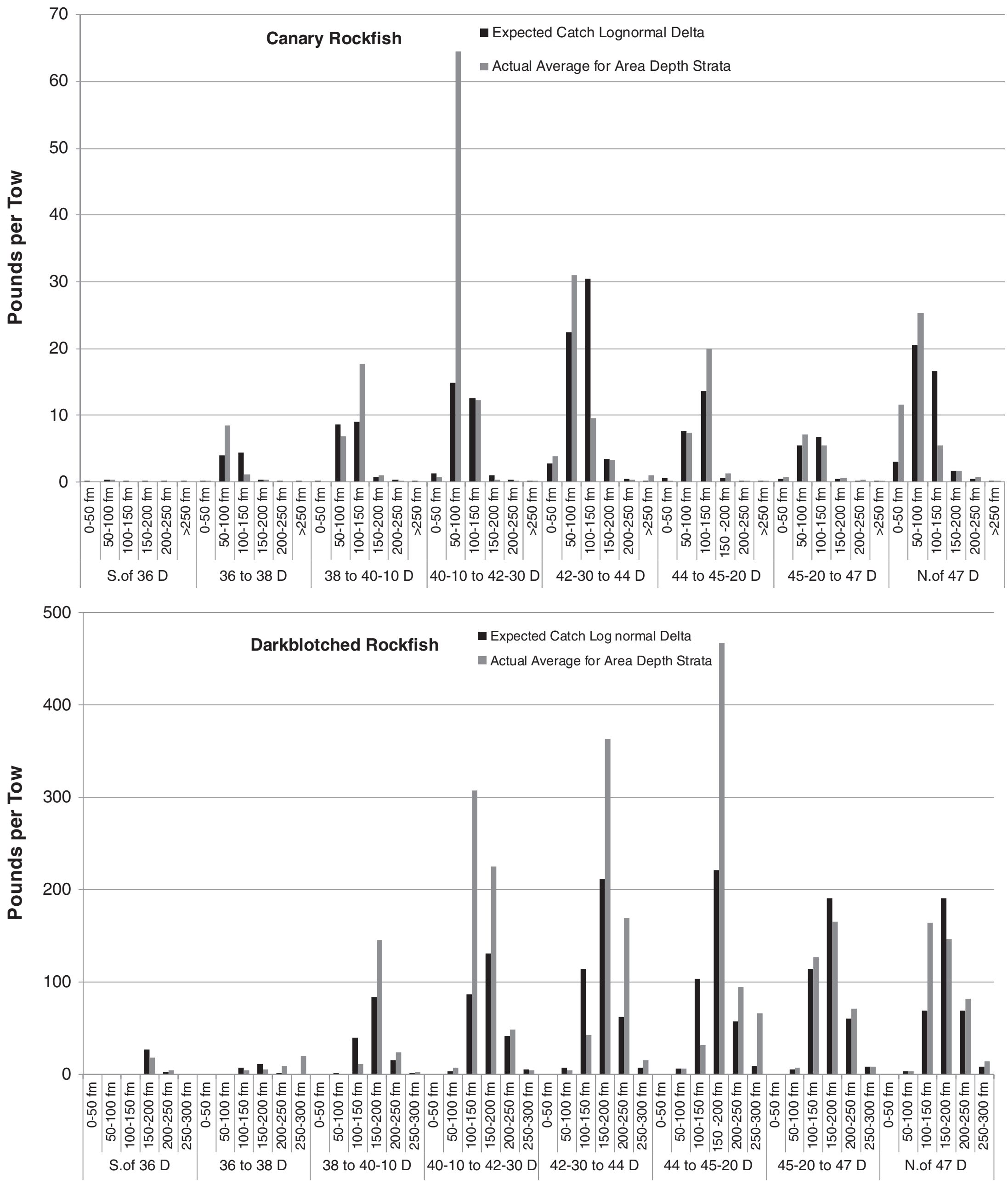

Fig. 4. Predicted and observed average catch per tow by latitudinal and depth strata for canary rockfish and darkblotched rockfish by.

some species such as bocaccio, cowcod and yelloweye rockfish, less than 10% of vessels caught any at all in 2011, and correlation between catch and initial quota allocation was very low.

While risk pools may reduce risk and allow fishermen to fish target species allocations more aggressively, they also reduce individual incentives to avoid bycatch and could even create a race for fish (to access the pool's bycatch quota before others use it up). The fact that the probability and amount of bycatch for individual fishermen in the LE trawl fishery is significantly affected by fishing decisions that also can be expected to affect their target catch rates and profitability suggests that fishermen should probably be cautious about joining risk pools, and designers of risk pools should think carefully about whether and how the design of the risk pool can address adverse selection and moral hazard problems. Keeping risk pools small and comprised of vessels fishing in a similar area will reduce adverse selection problems as well as moral hazard, and relatively small risk pools should be able to provide substantial risk reduction.

Even with small risk pools moral hazard could undermine the pools effectiveness. To mitigate moral hazard risk pools may need to require pool members to follow specified best practices that reduce bycatch risk. The risk pool that began operation in Central and Northern California in 2010 did in fact designate a set of low, moderate and high risk fishing areas with access to high risk areas prohibited and special rules for fishing in moderate risk areas (Michael Bell, personal communication, October 18, 2010). These areas were based on the collective knowledge of the fishermen in the risk pool. However, this mapping process might benefit from a more objective statistical approach that utilizes a greater amount of data. Risk pools can also facilitate sharing of information amongst members to improve their ability to avoid bycatch and, in fact, risk pools might require sharing

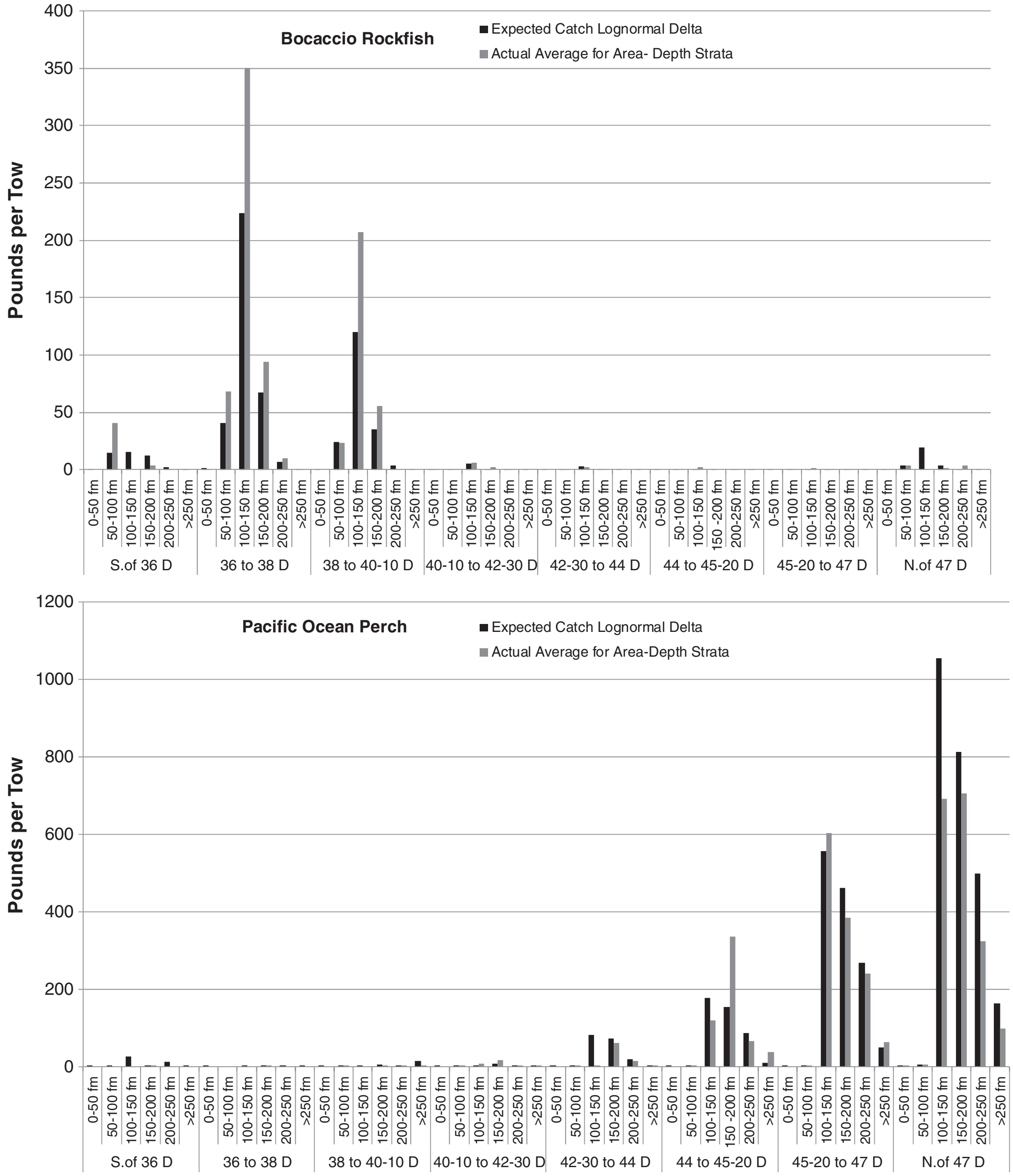

Fig. 5. Predicted and observed average catch per tow by latitudinal and depth strata for bocaccio rockfish and Pacific Ocean perch.

of this information and specific responses to it (e.g., moving away from hotspots).

Fishing rules prescribed by risk pools to constrain bycatch could be either ineffective or overly effective and thus too costly. It is unlikely that they will be optimal in the sense of balancing costs and benefits of bycatch avoidance or resulting in optimal bycatch avoidance behavior. Residual moral hazard might remain if fishermen have private information and if some methods of reducing bycatch risk are difficult to monitor and costly to the fisherman. It could be important to maintain some individual financial incentives to reduce bycatch. Insurance policies commonly require deductibles or coinsurance as a means to reduce moral hazard, and risk pools may want to do the same (e.g., by requiring individuals to cover some of the cost of bycatch quota up to some limit). In cases where a small level of bycatch is common, but large bycatch events are relatively rare (e.g., canary, widow) a shifted deductible that is incurred only above a certain level of bycatch but also caps total exposure may provide more effective incentives to reduce moral hazard. Shifted deductibles have been used in health insurance plans (van Kleef et al., 2009).

Experimental research has shown that demand for insurance by individuals, and supply by insurers as well, is impacted not only by uncertainty and quantifiable risk, but by ambiguity (i.e., uncertainty about one's uncertainty). Hogarth and Kunreuther (1985, 1989) find that

> *(1) the pricing decisions of both firms and consumers are sensitive to ambiguity; (2) sensitivity to ambiguity varies as a function of the probability of the potential loss specifically, aversion to ambiguity decreases (relatively speaking) as probabilities of losses increase and, in the case of consumers, can result in ambiguity preference for high probability-of-loss events; and (3) firms show greater aversion to ambiguity than consumers.*

These observations may have some important implications for which species fishermen may be most interested in including in risk

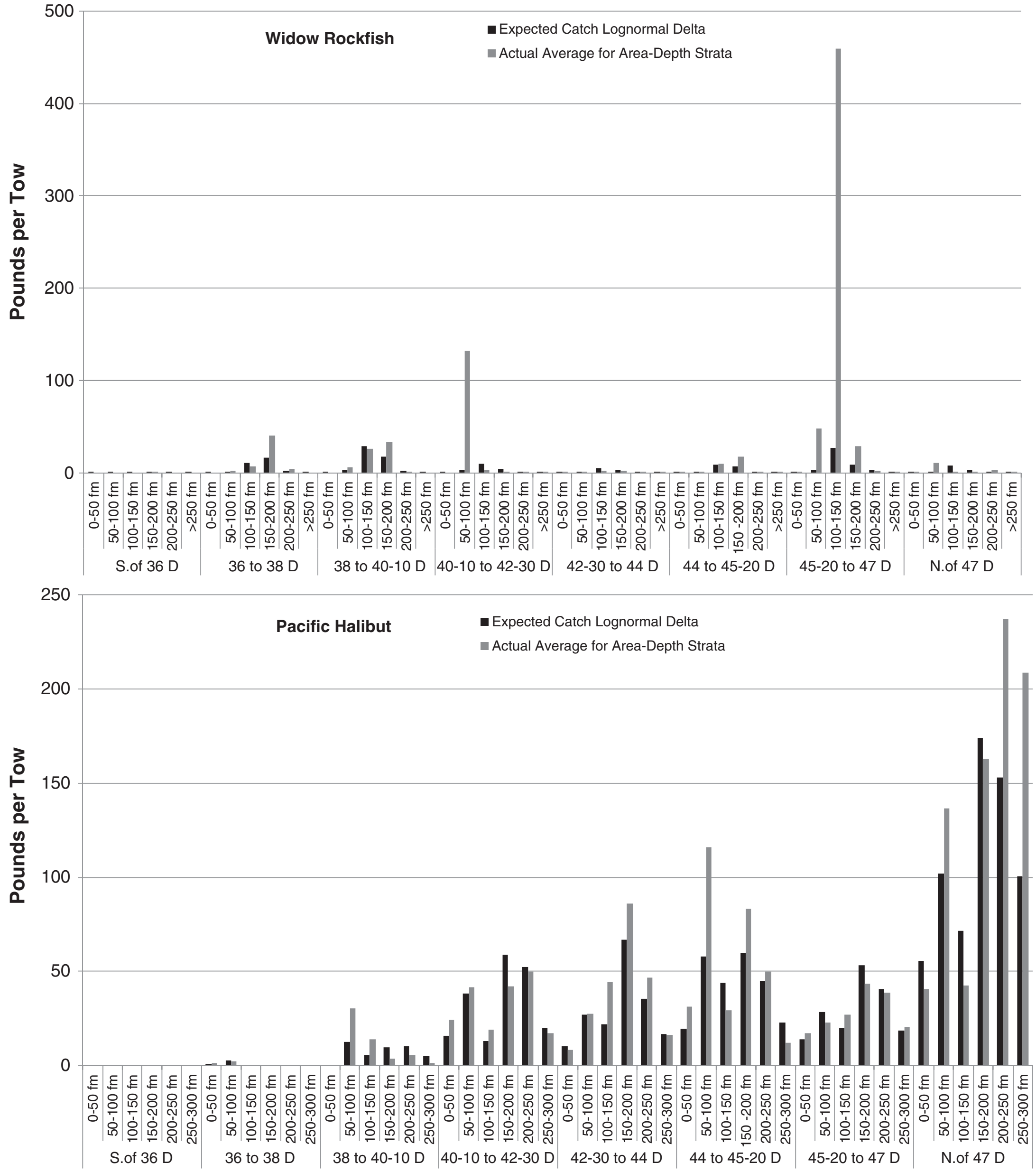

Fig. 6. Predicted and observed average catch per tow by latitudinal and depth strata for widow rockfish and pacific halibut.

pools. The statistical models discussed above suggest that the predictability of expected bycatch varies substantially by species. If ambiguity is less of an issue for higher probability bycatch species then this might further reinforce reasons to leave a species like Pacific halibut out of risk pools and concentrate on species like widow rockfish for which bycatch is both highly variable and unpredictable.

Risk pools that do not include the entire fleet do not eliminate the interdependent risk that the fishery will be shut down if the overall TAC is reached due to catch by non-pool members. This risk, if believed to be substantial, could motivate a race for fish that would undermine the operation of the risk pools and the ITQ system as a whole. Risk pools can counteract this by including more or all of the fleet; however, this also increases moral hazard and could require including individuals that are high risk and bring little QP to the risk pool. Another option would be for the risk pools to acquire a market insurance policy that would provide some compensation for unused target species quota in the event that the TAC is breached before target quota is used up (e.g., see Holland, 2010). Alternatively regulators could indemnify the risk pool from the actions of others (e.g. not close it down as long as it had not used up its own QP), but this may not be legal in the US.[11] Multi-year TACs that effectively allow more variability of total catch across years might also mitigate this problem though the legality of multi-year TACs is also questionable.

Acknowledgements

We would like acknowledge the West Coast Groundfish Observer program for providing observer data to support this analysis, and, in particular, to all the observers who collected data over the years at significant personal risk.

[11] The Magnuson-Stevens Act requires that annual catch limits be set for all managed species to ensure catches each year do not exceed those associated with the fishing mortality rate associated with maximum sustainable yield or lower in case of rebuilding species.

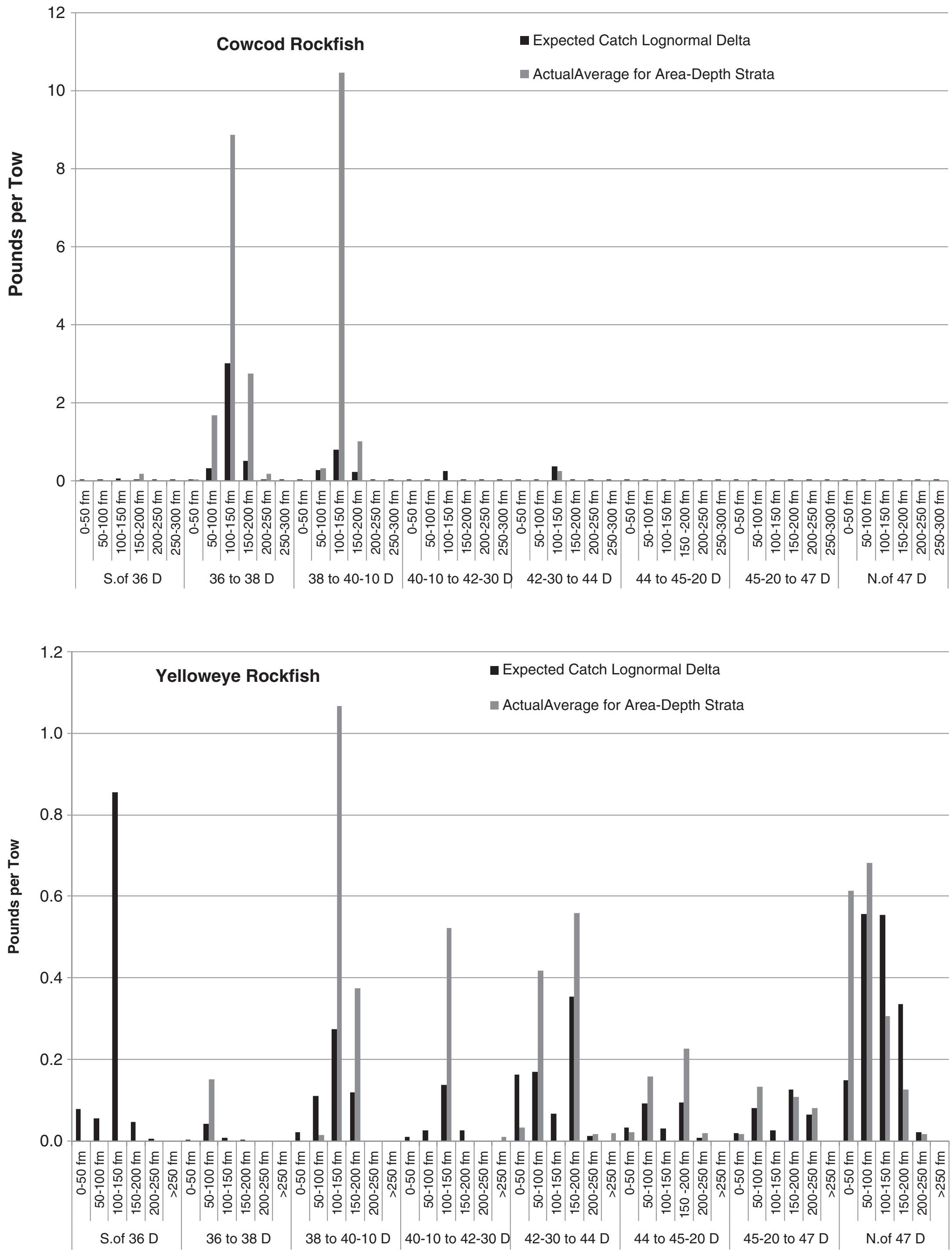

Fig. 7. Predicted and observed average catch per tow by latitudinal and depth strata for cowcod rockfish and yelloweye rockfish.

Table 6
Number of quota owners and quota users and correlation between initial quota allocation and catch by species in 2011.[12]

Quota species	Number of quota owners	Number of vessels with catch (152 Total)	Correlation between catch and intial quota—vessel owners only	Correlation between catch and intial quota—all quota owners
Bocaccio rockfish	59	10	(0.00)	(0.00)
Canary rockfish	128	56	0.22	0.16
Cowcod	59	4	0.06	0.06
Darkblotched rockfish	128	84	0.39	0.39
Pacific ocean perch	128	69	0.51	0.51
Widow rockfish	128	60	0.20	0.18
Yelloweye rockfish	124	13	0.06	0.03

[12] These are based on preliminary data for catch which may not include some discarded fish or fish caught at the end of 2011.

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