An Experimental Analysis of a Points-Based System for Managing Multispecies Fisheries

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An industry group has proposed a novel system for managing the Northeast Multispecies Fishery. Each harvester would be endowed with a budget of points, and each species would have a "point price," or number of points that must be paid out of his budget when landing that species. By varying the point prices throughout the season, management could redirect effort across species. This paper presents a benchmarked experimental testbed of this management system, and shows that harvesters do respond to point prices, which can be chosen to support harvest of most of the allowable catch of each species without severely over-harvesting any of them.

Key Words: multispecies fishery, points system, economic experiment, quota, derby

The Northeast Multispecies Fishery has proven to be a particularly challenging management problem.[1] It consists of 15 jointly harvested groundfish species, in 19 stocks, distributed over a large area and pursued by highly heterogeneous harvesters, with varying ports, vessel size, gear type, and preferred target species. Many of the stocks, including some economically valuable ones, are abundant, but other stocks are badly depressed. The fishery is currently (until May 2010) managed by a system of transferable days at sea, which constrains how much time vessels may spend harvesting, combined with daily trip limits for certain species. Harvesters find this system unsatisfactory because the allocations of days at sea are limited by the most depressed stocks, meaning that harvesters are not allotted time to harvest much of the biologically determined total allowable catches (TACs) of many of the most valuable stocks. As a result, industry and regulators are interested in identifying alternative management systems that are politically feasible[2] and provide better opportunity for harvesters to profit from abundant stocks, while allowing recovery of depressed stocks.

One novel approach has been developed by the Northeast Seafood Coalition (2006). Rather than an initial allocation of quota shares in each of the stocks, this so-called "Points System Proposal" would establish an initial allocation of "points" to each harvester. Although this initial allocation would be based on landings history, individuals would not be granted an access privilege to any particular amount of any species of fish. Instead, the points system proposes to assign a "biological

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[1] See the New England Fishery Management Council's "Northeast Multispecies Fishery Management Plan" at http://www.nefmc.org/nemulti/index.html for more information about the fishery, which is constantly evolving.

[2] This fishery has been historically managed by input regulation, and harvesters are united against any quota-based system. While individual transferable quotas may best achieve management goals, the management challenge here is to identify a non-quota system that does nearly as well.

point value" (BPV) to each of the stocks and fishermen would "spend" their points based on what they catch. In this manner, a weak stock with a low TAC would be assigned a higher (perhaps much higher) BPV than a rebuilt stock or one that has a higher TAC; this would encourage harvesters to focus their effort on stocks that cost fewer points.[3] As proposed, the BPV would be adjusted periodically in response to current harvest activity and stock abundance to assure that TACs would not be exceeded. This system would operate much like the Federal Reserve's overnight lending rate policy, wherein a regulatory authority can control the actions of agents in an economy by continuously adjusting key price ratios, thus altering behavioral incentives.

From an economic perspective, the points system has some of the same desirable features associated with individual transferable quota (ITQ) programs (Arnason 2002). Specifically, fishermen would have an incentive to maximize the value of their allocated points instead of maximizing catch. Further, it creates an interest in the longer-term health of the resource to increase the value of the allocation. The industry also feels that the points system also offers some economic flexibility that an ITQ would not. Under an ITQ system, individual harvesters would need to enter the quota market to obtain the desired portfolio of quota for the fishing season. Changing the portfolio to match realized catch would require the harvester to go back to the quota market and incur the potentially high transaction costs of acquiring or selling quota to achieve the correct balance of the 19 quota instruments. The points system would reduce these transaction costs and would afford harvesters greater flexibility to adjust business planning on an annual or in-season basis.

This paper implements an experimental proof-of-concept testbed for the points system that evaluates whether, even in a simplified environment, periodic point price adjustments can be identified—and whether harvesters have sufficient control over their harvests to respond simultaneously to market and point prices—to support fishing choices that harvest a significant portion of the TAC of abundant species, without badly over-harvesting depressed stocks. This will complement Truong, Jiao, and Azadivar's (2006) computer simulation of the effect of the program on stock levels.

The experimental treatment addresses two concerns raised by the National Oceanic and Atmospheric Administration's (NOAA's) Multispecies Plan Development Team (PDT) in assessing the points system: that harvesters might discard species that yielded low profit per point, not wanting to spend their points on low value species; and that incorrect point prices might induce derbies. That is, seeing an underpriced species, harvesters may race to target it, and catch very high volumes before the price can be corrected. This sort of derby can decrease fishery profits in two ways. First, the rapid pursuit of fish with a high ratio of market price to point price can induce harvesters to spend more money in pursuit of underpriced species, traveling to distant fishing grounds, or investing in larger vessels, to more fully exploit this species before its point price goes up. Second, in so doing, they may meet or exceed the annual TAC for that species before the price can be adjusted. In this case, the point price after the adjustment will rise dramatically. This can leave the market with a very low supply of the initially underpriced species for the balance of the season, and make effectively off-limits still-available fish stocks that are often jointly harvested with the initially underpriced species.

Similar experiments have been used to evaluate other proposed fishery management measures. The North Pacific Fisheries Management Council used an experiment to evaluate arbitration rules between harvesters and processors in the Bering Sea/Aleutian Island crab rationalization (North Pacific Fishery Management Council 2003). The New Zealand Ministry of Fisheries used experiments to support its choice of auctions for residual quota for new species (Anderson and Holland 2006), and experiments have been used to develop an understanding of price formation under alternative rules of trade in transferable allowance markets (Anderson 2004, Anderson and Sutinen 2005, 2006). This paper expands on those projects by examining harvesting strategies, rather than market mechanisms that have been the focus of previous work.

The next section describes the experimental design and treatment parameter sets. The price ad-

[3] "Biological point value" is the language of the proposal, though in reality abundance is only one factor that will determine point prices that effectively manage effort across species. A high point price may not be necessary to discourage harvest of a species if it yields low profits, or a high point price may be needed to reduce harvest of even an abundant species if it is highly profitable.

justment rule developed for the experiment is then explained. The section after that presents the experimental results, focusing first on harvesting choices and TAC exploitation, and then on individual responsiveness to point prices. The final section concludes with implications for implementing the points system.

The Experimental Environment

The hypotheses to be tested concern how harvesters alter their catch composition in response to changing ratios between the profitability and point prices of landing different species. The experiment captures this by asking subjects to choose among a set of "locations," each of which has a different composition of three "species."[4] In the "no discarding" treatment, subjects land everything they catch, but in the "discarding" treatment, subjects can choose to land a subset of their catch. Subjects earn money for participating in the experiments, and the amount they earn is proportional to the profits they earn from fishing.

In each experimental session, groups of 8 or 9 subjects share a set of four fishing locations, and have the option to stay home. On each day of a 10-day fishing season, each subject chooses a location to fish. Each subject has a cost (i.e., travel cost) associated with each location. When a subject chooses a location, she pays the associated costs and "catches" a random draw of three species of fish from that location; subjects are provided expected catch information for each location. The subject sells her landings to the experimenter at the market price posted for each species. (In the discard treatment, subjects can choose which subset of catch they wish to land, discarding the rest.) She keeps her revenue from selling landings, less the location-specific cost, as profit.

To implement the points system in this simulated fishery, subjects begin each season with an endowment of points. Each species has a posted total allowable catch (TAC) that is explained to subjects as "a harvest goal for that species... [that] represents fish that can be landed safely, without harming the fishery." The point price for each species represents the number of points that must be redeemed for each pound of that species landed. Initial point prices are determined by the parameter set used, and subjects are told that the point price will change after the fifth day of the season. Specifically, the instructions describe the basis for changing point prices:

> Point prices will change to encourage choosing locations that will come closest to reaching the TACs for all species. This means that if, in the first 5 days, all species are approaching their TACs at the same rate, it is likely that relative point prices will not change very much, but if one is approaching its TAC much faster than others, its relative point price will increase.

To help subjects track the effect of the group's harvesting on likely future point prices, the cumulative landings of each species, and remaining TAC, are posted at the end of each day.

Figure 1 shows the subject interface for the discarding treatment; the no discarding treatment is similar. Locations are arrayed across the upper section of the screen, and provide information on the cost, expected catch, expected points redeemed, and expected revenue associated with that location. The lower part of the screen provides information on the fishery, including the TAC and cumulative landings of each species; the market, including the price for landings and the point prices associated with each species; and the subject's "boat," which reflects the subject's landings and tracks individual profits.

When a subject clicks on a location, a pop-up box notifies her of her catch, and in the discard treatment gives her the option of choosing how much of her catch of each species she would like to land.[5] In the event that a subject does not have enough points to cover her catch, her catch of all species is scaled proportionately to exhaust her points. In the discard treatment, she can adjust this recommended scaling for a more profitable landing.

Experimental Parameters

Testing the specific hypotheses about discarding and price-induced derbies will require treatments

[4] Locations within the experiment reflect variations in species composition and non-target catch rates, thus capturing not only geographic location, but also gear-setting techniques and depth choices made by harvesters in the field.

[5] To avoid associating any ethical value to discarding, in the discarding treatment subjects were told simply that they could choose to "land none, some or all of your catch of each species," and that landings determined revenue and how much was subtracted from the TAC.

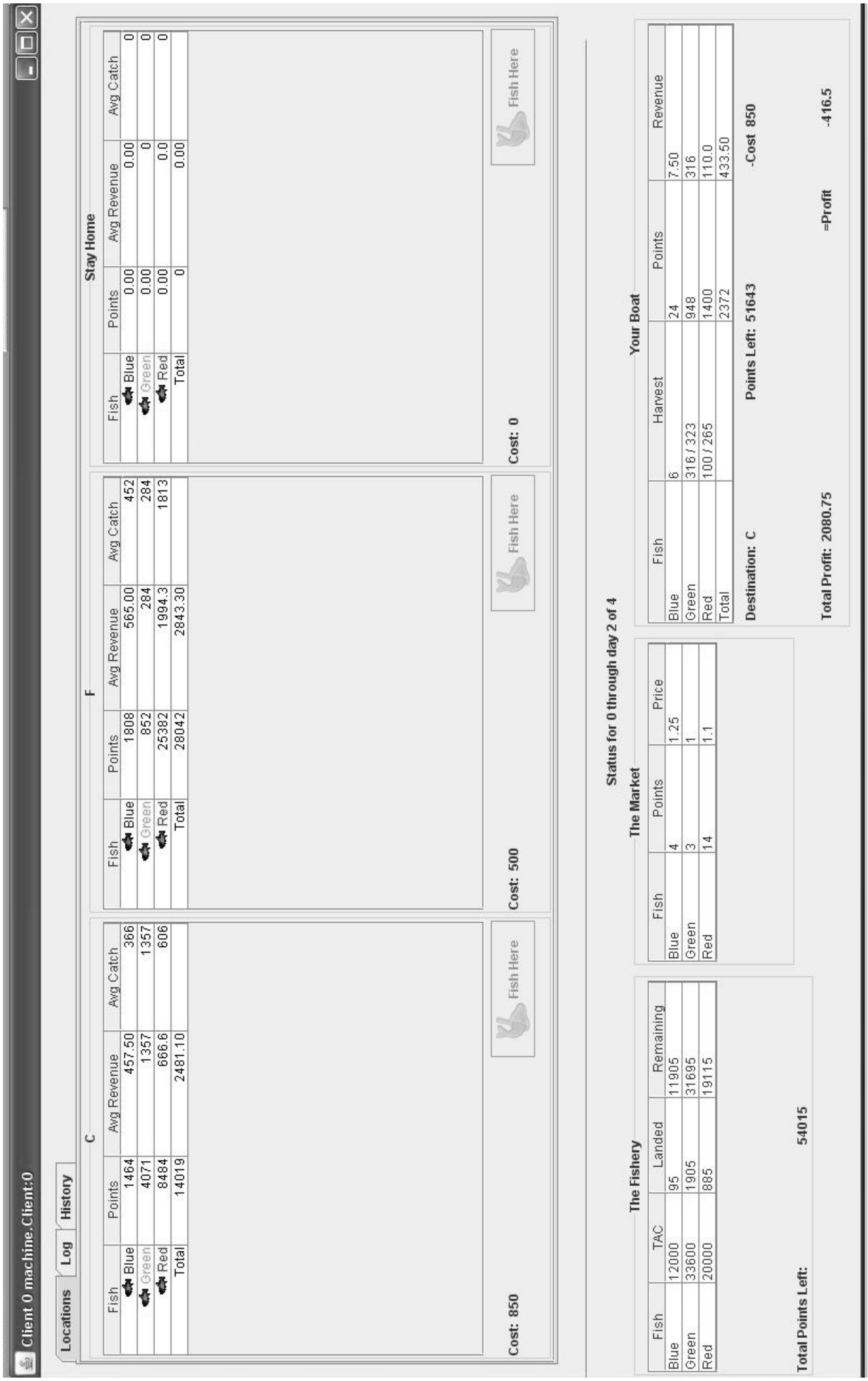

Figure 1. Screen Shot of Subject's Interface (during three-location demonstration round)

with different relationships among initial stock abundance, market prices, and initial point prices. Derbies should be most likely when some species are initially significantly undervalued, and discarding should be most likely when some species are relatively expensive. Thus, we must define a set of alternative locations and parameter sets of TACs and initial point prices in which this range of outcomes is predicted. The five available locations are described in Table 1.[6]

The top section of the table shows the average pounds of each species caught in each location. The primary tension leveraged in the experimental design is that between the profitability advantage of D, and tight TACs on green fish that make B the optimal choice. When subjects select a location, they receive a random draw from 100 actual fishing trips taken from logbook data, where each area corresponds to a region of the Northeast multispecies fishery.[7] Because the actual harvests are highly variable, so too are the subjects' harvests. Subjects were told there would be considerable variation because their harvests would be based on actual trips, but we did not provide them with variance-covariance matrix information for each location.

The four parameter sets described in Table 2 test the extent to which choice behavior can be controlled by adjusting point prices. They are named to reflect the optimal location choice pattern. Set D is determined by multiplying the expected catch at D by eight days times the number of subjects to get the TAC, and choosing point prices such that D is optimal, and multiplying point prices by the expected catch times eight periods to get point endowments. Set B is determined similarly, but with location B, which has far fewer green fish. Sets BD and DB have TACs set by multiplying the expected catch at each location by four times the number of subjects. Set BD has initial point prices so that location B is optimal, and has an expected set of changed point prices that support location D and serve as a basis for determining point endowments. Set DB sets the point price of green low enough that D is tempting, though it leads to possible inefficiency.

Note that for BD and DB, the efficient harvest levels are such that four periods of D and four periods of B achieve harvest efficiency regardless of the order in which those locations are visited. Thus, if all subjects initially target D four times in set BD, for example, they will simply be going into the second half of the season with fewer points than anticipated. The point price adjustment algorithm will select relative point prices so that the optimal choice is B, but will scale the point prices to a lower level, taking into account the smaller number of outstanding point balances. Inefficiency can still arise in two ways. First, the potential for inefficiency arises when some subjects get the order wrong but others do not. The subjects who adopt less point intensive strategies (choosing location B in this example) will have a greater share of the outstanding points after the point price change, and thus will have greater flexibility in selecting the most profitable locations a greater number of times after the change. Second, enough harvesters could select D in all five initial days, leaving an insufficient quantity of the green TAC available for the price adjustment algorithm's new price to select four harvests at B as the optimum outcome, and thus the resulting point prices could lead to inefficient total harvest.

In each experimental session, subjects participated in eight 10-day fishing seasons. The parameter sets were presented in order of increasing strategic complexity, so subjects first played with parameter set D, then D a second time, then B in seasons 3 and 4, BD in seasons 5 and 6, and DB in seasons 7 and 8.[8]

Price Adjustment Model

Since revising point prices is a key element of the points system proposal, and is key to the behavioral incentives being tested in the present study,

[6] Expected harvests do not vary with current or previous location choices of other subjects, reflecting that TACs are a small portion of overall biomass and that the species being modeled are schooling, so incremental stock depletion does not diminish catchability.

[7] Blue fish are haddock, green fish are yellowtail flounder, and red fish are cod. Location A corresponds to Inshore George's Bank, B to Mid-George's Bank, C to Inshore Gulf of Maine (South), and D to Offshore George's Bank.

[8] While this design does not let us test for order effects, pilot experiments suggested that the primary effect of experience is improved understanding of the environment, and that presenting parameter sets in order of strategic complexity gave the points system its "best chance"; because treatment transitions require a change in strategy, any "momentum" strengthens our tests. This environment does not feature preference discovery or the development of group norms that often drive confounding treatment order effects in experiments.

Table 1. Expected Landings of Each Species at the Available Locations

Location	A	B	C	D	Stay Home
Avg. blue	7,421	10,709	366	5,493	0
Avg. green	2,696	2,680	1,358	9,216	0
Avg. red	5,196	7,089	607	8,492	0
Cost	1,800	2,200	850	2,500	0
Exp. profit	15,888	21,664	1,633	22,923	0

Table 2. Experimental Parameter Sets

Species	TAC [a]	Initial Point Price	Market Price	
SET D				POINT BUDGET: 650,000
Blue	521,000	1	1.25	Parameters allow subjects to select location D, the most profitable, eight times, and stay home twice. If followed, relative point prices will not change.
Green	567,000	5	1.00	
Red	536,000	3	1.10	
SET B				POINT BUDGET: 650,000
Blue	721,000	3	1.25	Parameters allow subjects to select location B eight times, and stay home twice. However, if subjects select the more myopically profitable D, they will draw down the TAC of green and its point price will spike.
Green	191,800	12	1.00	
Red	480,400	5	1.10	
SET BD				POINT BUDGET: 815,000
Blue	520,200	3	1.25	Parameters allow subjects to select location B four times before the price change and D four times after the price change, and stay home twice. However, if some subjects ignore the point price and choose D, they will have fewer points and be able to make fewer trips when new point prices direct them to B.
Green	384,000	22	1.00	
Red	512,000	5	1.10	
SET DB				POINT BUDGET: 650,000
Blue	520,200	4	1.25	Parameters allow subjects to select location D four times, and then B four times, and stay home twice. However, the initial point prices induce a derby on green though D. If green is chosen five times by everyone, green's point prices will spike, making B and D unaffordable.
Green	384,000	1	1.00	
Red	512,000	9	1.10	

[a] TAC listed is for 8-subject session. Nine-subject sessions scaled the TAC proportionately.

it is necessary to develop a model of point price adjustment. This model will serve two research purposes. First, it produces predictions which can be used to parameterize the experimental environment, and that serve as specific hypotheses to be tested. Second, it provides a systematic, neutral process for determining price changes during the experiments, so subjects can strategize against a fixed (if incompletely understood) environment, without fear that the experimenter is arbitrarily or unfairly manipulating prices. The model also serves the practical purpose of establishing a testbed, in which the problem of price adjustment must actually be considered and implemented.[9]

The points system proposal put forward by industry does not suggest how point prices might be adjusted; a model must be developed from scratch. The model used in the experiment selects a target harvest outcome from among those available to harvesters (i.e., an expected harvest from a feasible combination of location choices) and identifies a price that supports that outcome as an optimum for the harvester.[10] The first step in this process is to identify, for a set of market prices and set of available locations for each harvester, the set of aggregate harvests that are supportable by some point price vector; not all possible combinations of location choices can be the result of agents optimizing against a point price vector. For a given market price p, the set of possible outcomes is

$$\Omega = \left\{ \begin{array}{l} x \in \sum x_i : \exists \rho : x_i \in \\ \quad \left\{ \max\limits_{x_i} px_i - c_i(x_i) \;\; st \;\; \rho x_i \le B_i \right\} \forall i \end{array} \right\},$$

where x_i is the vector of i's landings of each species, ρ is the point price vector, $c_i()$ is i's cost function, and B_i is i's (remaining) point budget for the fishing season. This budget is necessary to induce optimization solutions that do not pursue the same location in every trip, as it is the interaction of limited time and limited points that requires harvesters to develop multi-trip strategies to maximize their profit. Thus, Ω is the set of total harvests, across all harvesters, that are supportable by some point price.

For purposes of the experimental environment, Ω is constructed by evaluating a wide range of possible price vectors and determining the harvesters' location choices (and thus expected harvest) for each price vector. By fixing a point budget and looping over a large range of point price vectors, the set of point prices (i.e., point price ratios) that support each possible expected harvest combination as an outcome can be established.[11]

When it is time to adjust the point price, the manager chooses a feasible harvest $\omega \in \Omega$ that most closely matches her target for the fishery for that period. "Most closely" implies that the manager must make trade-offs between falling under the TAC for some species and exceeding the TAC for others, using some scoring rule. In the experiment, the target harvest was the TAC remaining, and elements of Ω were scored by a minimum squared deviation criterion, with TAC overages penalized by a factor of four relative to TAC underages. Other criteria are possible.

Having identified ω^* as the most desirable of the feasible outcomes, the manager then chooses a point price vector ρ from the set of point price vectors that support ω^* as an outcome. For the experiment, the ρ with the highest price level for the scarcest species was chosen. This ρ gives one set of price ratios that will support the choice of ω^*; however, because of the time associated with constructing Ω, it was necessary to calculate it prior to learning the actual number of points remaining in the experiment, with a conjectured number of total points remaining. Multiplying ρ by the ratio of the actual number of points remaining to that used in constructing Ω yields point prices which support ω^* in the experiment.

Experimental Results

Experiments were conducted using undergraduate students recruited from an email list of subjects who had previously expressed interest in participating in experiments, as well as from economics, resource economics, business statistics, and nutri-

[9] This problem is not trivial. While the Fed worries about one price ratio (the price of money today to money tomorrow) with fluid money markets, the points system for N species requires attention to $(N+1)N/2$ price ratios in an environment where not all harvest combinations may be feasible.

[10] A tatonnement adjustment model motivated by Scarf (1960), wherein prices change in proportion to excess demand, was also considered; although the points system is not a tatonnement pricing mechanism, Anderson et al. (2004) show that prices do evolve consistent with the predictions of Scarf's model, even in laboratory institutions where disequilibrium transactions are allowed. This was rejected for the experiment because differential price changes may not have been sufficient to motivate changes in the mix of discrete locations chosen.

[11] For some harvest combinations, the set of supporting point price vectors may be empty. For many combinations, the set has many elements and one must be selected.

tion courses at the University of Rhode Island. We collected data from seven inexperienced groups (three sessions of two groups, one of one group) and two experienced groups in the no discarding treatment, and four inexperienced groups (two sessions of two groups) and two experienced groups in the discarding treatment. Subjects in sessions with multiple groups had their groups reshuffled between seasons. Experienced subject sessions did not control for the treatment in which previous experience was gained.

Data Overview

Figures 2a and 2b show the distribution of location choices for subjects in the first five days of the no discarding and discarding treatments. Each figure shows eight bars arranged in four pairs. Each pair corresponds to a parameter set; the left bar within the pair is data from the inexperienced subject sessions (aggregating the two seasons of each parameter set within each session; differences are negligible), and the right bar is experienced sessions.

Looking at the data in all parameter sets, there are two key observations regarding location choice. First, incentives are an important driver of location choice, as the most profitable locations—B and D—are the most frequently chosen, and "Stay Home" and C (which yield little or no profit) are rarely chosen. Second, while the *ex ante* optimal strategy in each parameter set involves repeated selection of a specific location in at least four of the first five periods, no single location dominates the choices in any parameter set, even among experienced subjects; the data are noisy. This variability arises as individual subjects select different locations on different days within this challenging environment.

Despite the noise, there are observable differences in location choices among the parameter sets. Initial choice patterns in sets B and D are similar, with an emphasis on location B, which is even more prevalent among experienced subjects. This reflects a suboptimal response to the difference in TACs between the two parameter sets: in set D, green will be under-harvested and the relative point prices of red and blue will likely spike after day 5; in set B, green will be relatively over-harvested (because B constitutes only about half of choices) and its point price will spike after day 5. Between BD and DB, however, there is a marked shift from B to D in response to the low initial point price of green. With discarding, subjects are less likely to choose "Stay Home," and experienced subjects are less likely to choose low-intensity location A.

Figures 3a–3d show how much of each species was caught relative to the TAC, and when. Figures 3a and 3b show four sets of three bars, each associated with a parameter set. The bars reflect the total harvest and TAC, aggregated across all sessions.[12] The left bar in each set represents the blue fish (labeled with a B); the middle bar (labeled with G), green fish; and the right bar (labeled with R), red fish. Within each bar, the black segment indicates the amount of that fish caught in the first five days, before the price change, and the gray indicates the amount of that fish harvested after the price change. If total harvest is less than the total TAC,[13] the residual TAC is indicated by a white segment; if the total harvest exceeds the TAC, the overage is indicated by a crosshatched segment.

Comparing harvest patterns between parameter sets, the first five days' harvests are similar in parameter sets D and B, reflecting the similar distributions of location choices seen in Figures 2a and 2b. However, the revised point prices did lead to differential harvests, as harvests in set D reflect high levels of effort on all three species—likely through more intensive use of location D—and harvests in set B draw on proportionately less green—likely through more intensive use of location B. However, the non-optimal choices during the first five periods do prevent subjects from exhausting the TACs of all three species, leaving considerable green in set D and considerable blue in set B.

The more intensive use of location D in the first five days of set DB rather than BD can be seen in the amount of green fish harvested. However, the point price revision redirected effort successfully in both cases, and in both sets sub-

[12] This means that one group could exceed the TAC, but another leave a larger amount of TAC remaining, and it would be reflected as an aggregate underage.

[13] A file buffer error in the software prevented the recording of some subjects' data in the final day of some seasons. Absent information on this effort, the TAC used in the analysis is prorated to the data available, on a per-subject, per-period basis.

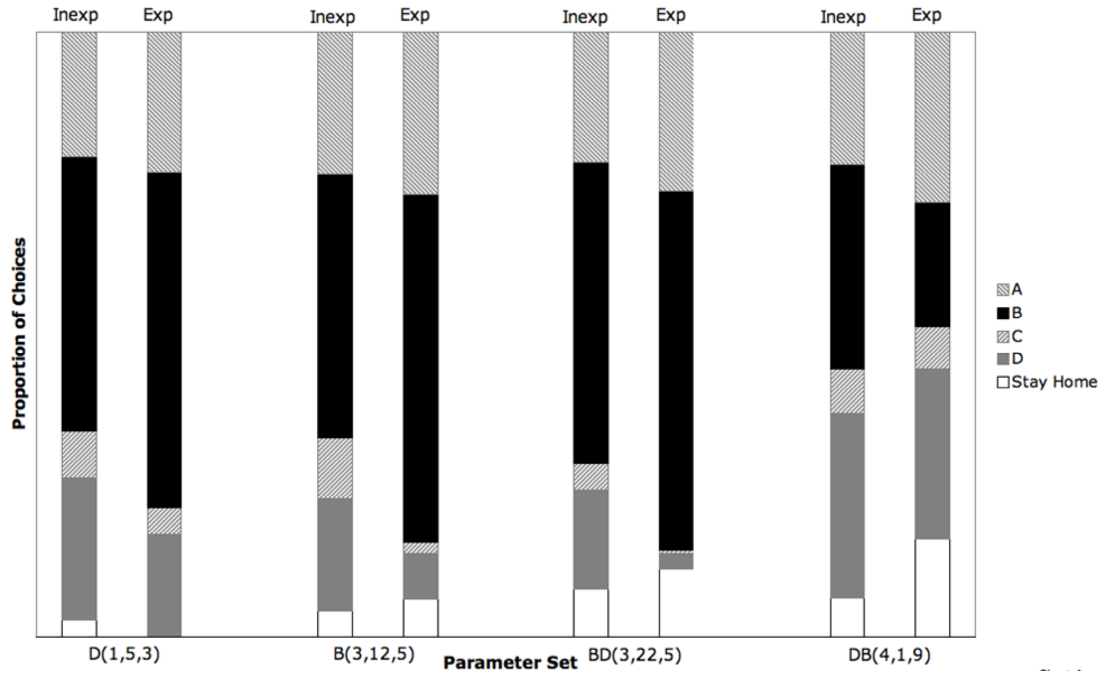

Figure 2a. Location Choices in First 5 Days Without Discarding

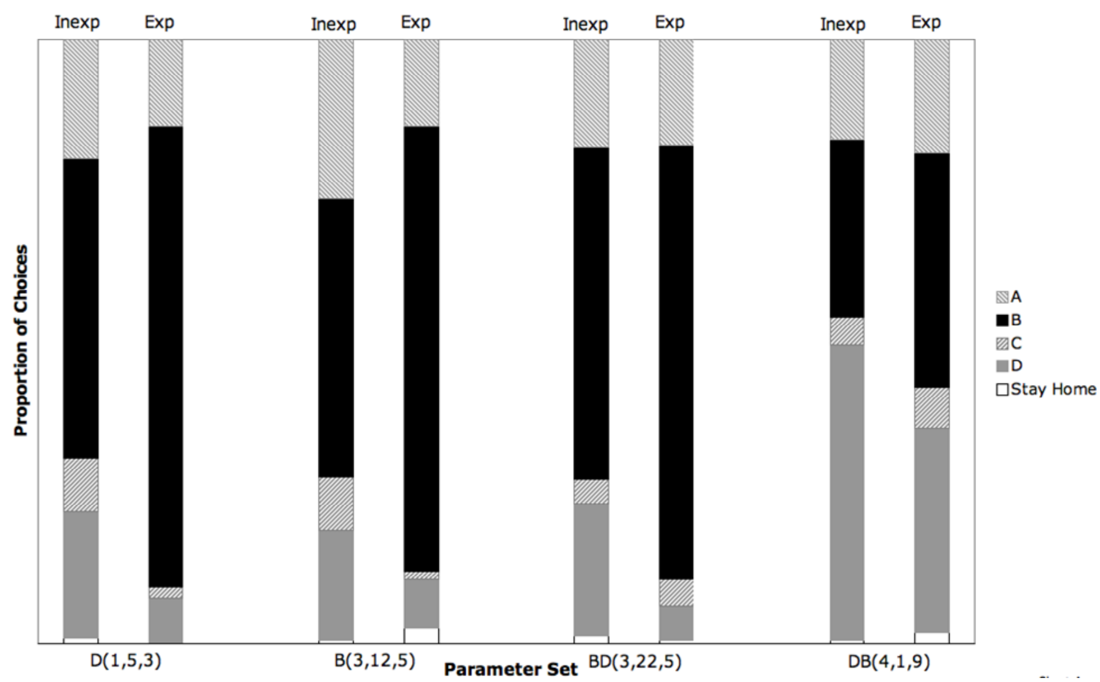

Figure 2b. Location Choices in First 5 Days with Discarding

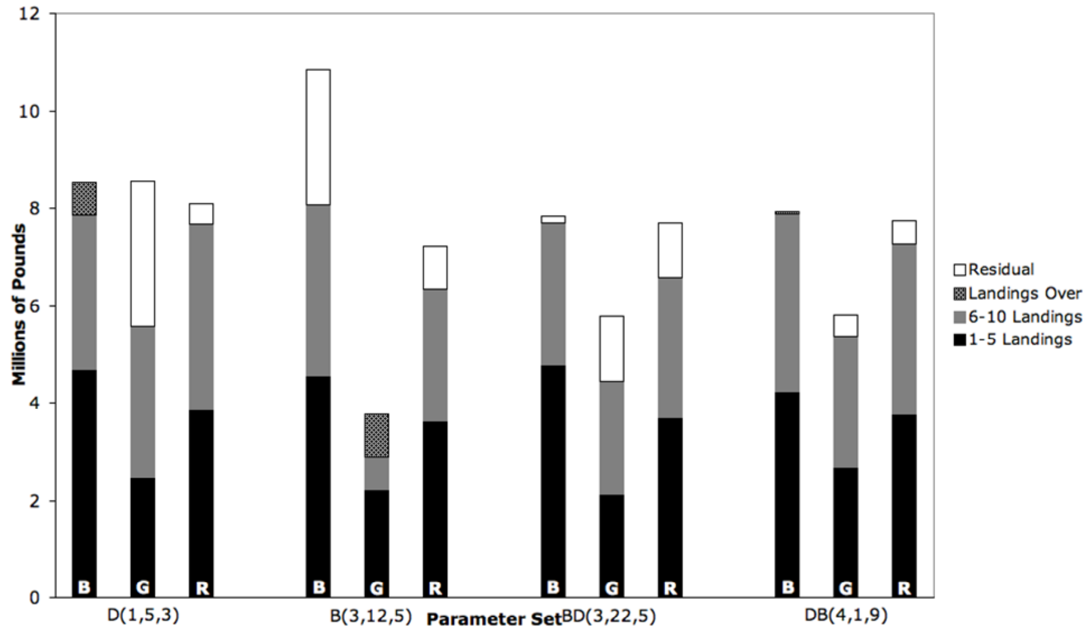

Figure 3a. Total Harvests Without Discarding

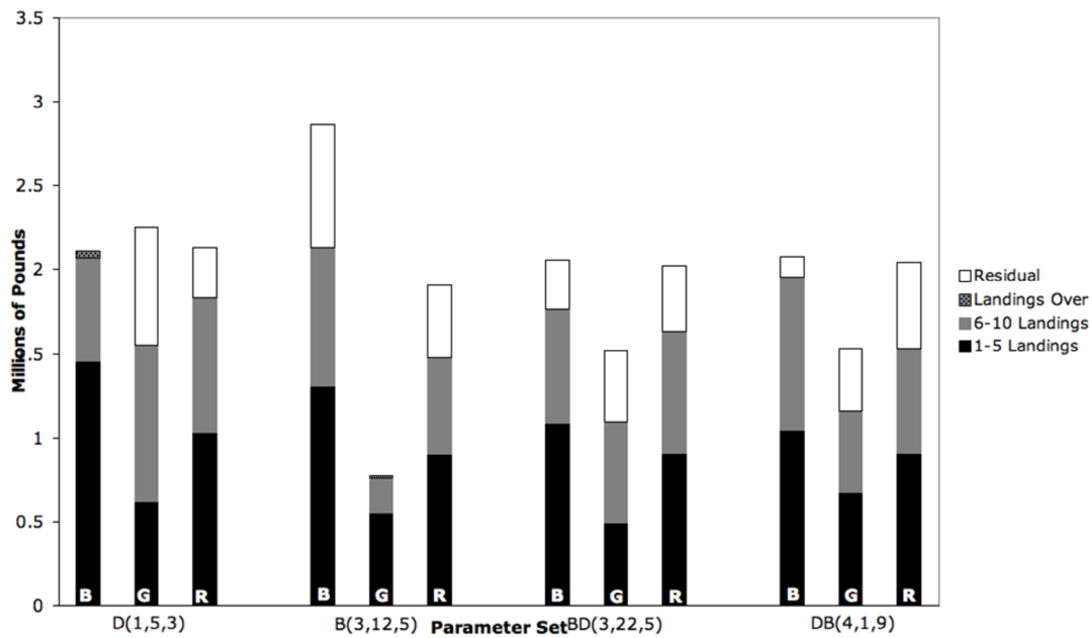

Figure 3b. Total Harvests Without Discarding (Experienced)

jects harvested a very significant portion of the TAC of all three species, with minimal overage.

Figures 3c and 3d have an additional layer of complexity to represent discarding. To the previous solid bars, slashed segments have been added to reflect discarded fish: black rising slashes indicate discarding during the first five days that still fell within the TAC; gray rising slashes indicate

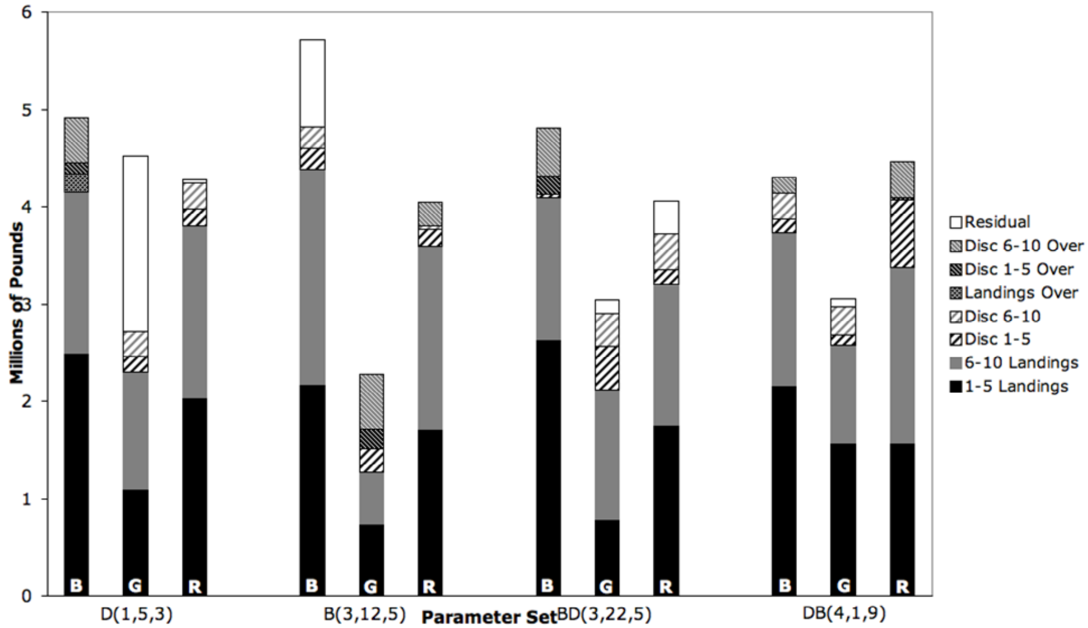

Figure 3c. Total Harvests with Discarding

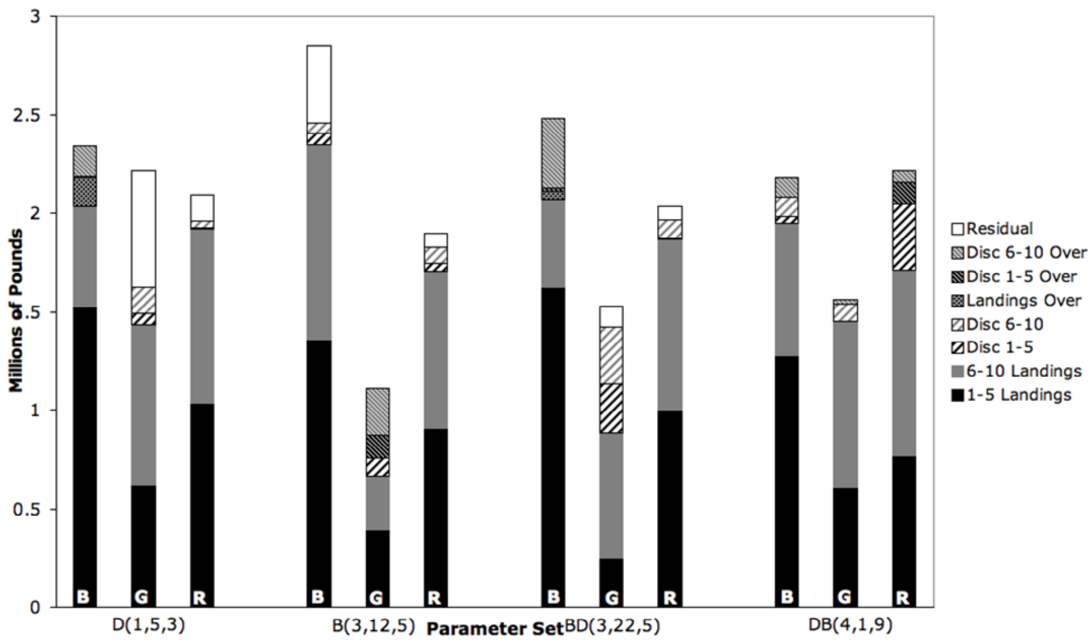

Figure 3d. Total Harvests with Discarding (Experienced)

discarding during days six to ten that fell within the TAC; black falling slashes indicate discarding during the first five days that would have exceeded the TAC had it been landed; and gray falling slashes indicate discarding during days six to ten that would have exceeded the TAC had it been landed.

Perhaps surprisingly, discarding behavior represented in Figure 3c reflects a relatively small impact of discarding on stocks: while discarding of most species happens, it is often still within the bounds of the TAC. The blue TAC is exceeded by landings alone in parameter set D and BD, just as when discarding was impossible. However, discarding leads to exceeding the TAC in green and (inexperienced) red in set B, and in blue and red in set DB. Interestingly, in set B there is considerable discarding during the first five days of the season, perhaps because point prices were so high, but subjects wound up landing a lot less green than in the no discarding treatment.

The point prices in Table 2 drive location choices for the first five days of every session, but the second five days' prices are determined by the price change algorithm and harvests during the first five days. Figure 4 shows the distribution of changed prices, as price ratios with Red = 1; the discarding treatment is indicated by hollow markers, though their distribution is largely similar to that of the no discarding treatment. The figure shows that parameter set B often has revised prices where green's price is relatively high, steering subjects more strongly toward location B from location D. The DB parameter set appears to have mostly lower price ratios, where all species have similar prices. The other treatments have new prices where green is some multiple of red (up to eight times), and blue is some slightly higher multiple.

The next sections use statistical models to establish how point prices affect location choices, whether incorrect pricing induces derbies on underpriced species, and whether the discarding opportunity influenced location choices.

Point Prices Affect Location Choices

Table 3 presents estimates of a multinomial logit model of the choice of location during the first five fishing days in each season, when the point prices are determined by the parameter set. In this model, the base location is D, the myopic profit-maximizing location. Thus, a positive coefficient reflects that an increase in a variable will make subjects more likely to choose the indicated location than location D. The point price variables *Green Points* and *Blue Points* are normalized—setting the point price of red fish to 1—because price levels vary to reflect the total available points, both at the beginning of the season and at the point price change; these magnitudes should not be a primary driver of location choice.

The first two lines of Table 3 indicate that location choice probabilities are highly significantly affected by point prices, with seven of the eight coefficients significant, six highly so. In particular, significant negative coefficients on *Blue Points* means subjects are much more likely to choose location D when the relative point price of blue is high, especially relative to location B ($p < 10^{-15}$). When the relative point price of green is high, subjects become much less likely to choose location D, preferring instead to choose B ($p < 10^{-6}$), A, or "Stay Home." Thus, when the relative point price of a species is high, subjects reassess the value of the locations where that species is abundant, and select other locations.

That other parameter set and treatment variables are significant in addition to prices suggests that choice patterns are also consistent with dynamic strategies that indicate that subjects are looking at more than just prices. That is, subjects are anticipating the price change, and their future harvest opportunities under the TAC, in picking their locations. The parameter set primary effects in the second section of Table 3 capture location choice in the first five days. The significantly positive coefficients indicate that subjects are much more likely to pick locations other than D in parameter sets B and BD, when green fish is limited. After the point price change (captured by the Day > 5 interactions), negative coefficients reflect that subjects shift significantly toward location D from locations A and B in parameter sets D and B, reflecting that there is ample TAC available. The significant effects in parameter set DB are discussed in the next section.

Derby Fishing

Parameter set DB was designed to test the effects of a derby on a fish species induced by prices that were temporarily too low. A chi-squared test comparing the distribution of location choices indicates that the distribution of location choices in parameter set BD is significantly different from that in set DB, despite their identical TACs ($p < 10^{-10}$ for inexperienced subjects, and $p < 10^{-13}$ for experienced subjects). This reflects subjects'

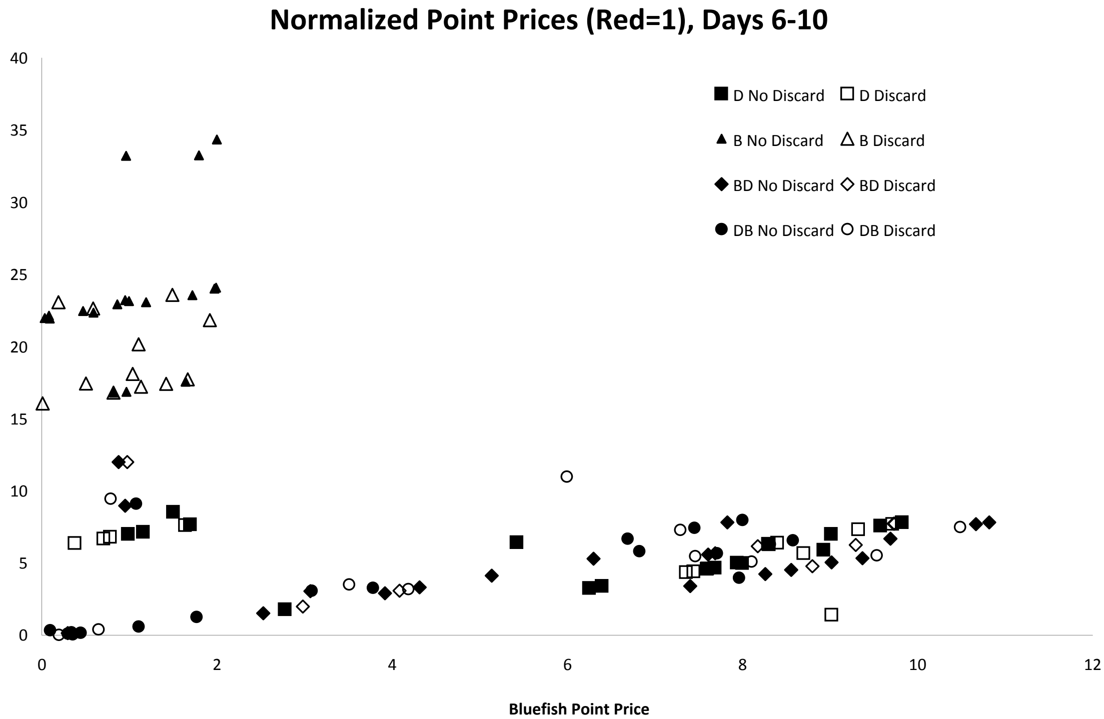

Figure 4. Normalized Point Prices, After Price Change

switching from choosing location B in set BD to location D in set DB, a relative "derby" on green fish in the first five days of parameter set DB.

Controlling for prices and treatment effects, the model in Table 3 indicates that locations B ($p < 10^{-3}$) and C ($p = 0.079$) are significantly less likely to be chosen than derby location D in the first five days of set DB. This means that subjects are opportunistically pursuing the underpriced green fish abundant in location D. This indicates that the subjects are choosing to pursue the underpriced green fish due to parameter-set–specific reasons beyond what can be explained by the relative prices alone.

However, it is important to note that, while there was derby fishing in the first five days of the fishing season in set DB, the TAC was not badly exceeded. Instead, the adjustment in point prices directed choices toward location B ($p < 10^{-8}$), for a net positive effect of 0.45 in the last five days, leading to a lower harvest of green fish. Thus, the points system does have a degree of flexibility to recover from initial pricing mistakes.

Discarding

Figures 2a and 2b suggest that the distribution of location choices did not dramatically change in most parameter sets between the discarding and no discarding treatments. Pooling observations in the first five days for each discarding treatment indicates that discarding did not affect choices in parameter set B (chi-squared $p = 0.562$ for inexperienced subjects, $p = 0.131$ for experienced) or in set BD ($p = 0.166$ for inexperienced subjects, $p = 0.276$ for experienced). In parameter set D, experienced subjects did significantly shift their effort toward location B in the discarding treatment ($p = 0.001$), perhaps hoping to save points for more trips with lower harvests of green fish, but inexperienced subjects did not ($p = 0.468$).

The opportunity to discard affected choices of both experienced and inexperienced subjects in derby treatment DB, though they reacted differently. Inexperienced subjects (chi-square $p < 0.001$) shifted effort from location D to location B with discarding. Experienced subjects ($p < 10^{-4}$) shifted

Table 3. Multinomial Logit Model of (Normalized) Price and Parameter Set Effects on Location Choice

	A		B		C		Stay Home	
Location	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Blue Points	-0.10**	0.021	-0.17**	0.020	-0.06**	0.024	-0.04*	0.022
Green Points	0.08**	0.023	0.10**	0.023	0.01	0.025	0.08**	0.029
Set B	0.47**	0.158	0.23	0.179	0.56**	0.235	1.11**	0.357
Set BD	0.33**	0.134	0.26*	0.139	-0.12	0.245	1.56**	0.395
Set DB	-0.14	0.175	-0.63**	0.191	-0.39*	0.224	1.00**	0.440
Day > 5	-0.72**	0.195	-0.98**	0.175	-0.35*	0.208	0.49	0.401
(Day > 5) × B	-0.90*	0.474	-0.77**	0.386	0.35	0.486	0.16	0.699
(Day > 5) × BD	-0.27	0.213	0.06	0.211	0.11	0.334	0.21	0.212
(Day > 5) × DB	0.17	0.200	1.08**	0.203	0.40	0.271	0.40	0.401
Discard	0.13	0.224	0.36**	0.195	0.11	0.263	-0.62**	0.240
Discard × B	-0.27	0.264	-0.17	0.229	-0.66*	0.338	-0.78*	0.407
Discard × BD	-0.51**	0.243	-0.33*	0.182	-0.42	0.341	-0.63**	0.312
Discard × DB	-0.67**	0.253	-0.66**	0.236	-0.54	0.365	-0.50	0.347
Experience	0.20	0.239	0.36**	0.167	-0.36	0.247	0.61**	0.168
Constant	-0.19	0.160	0.61**	0.146	-1.02**	0.183	-2.63**	0.409

Note: N = 9,905, chi-squared = 2,155.86. ** denotes coefficients with $p < 0.05$, and * denotes $p < 0.10$ (cluster bootstrapped standard errors).

effort from locations A and “Stay Home” in the no discarding treatment toward location B in the discarding treatment. This may reflect an evolution of strategy because, while the green fish caught in D can be discarded, location B offers more of the other species that can be landed and sold.

The logit model in Table 3 also indicates there is some effect of the discarding treatment in parameter sets BD and DB. In the derby-inducing parameter set DB, subjects do target underpriced green fish more aggressively in the discarding treatment, as they are even more unlikely to select location B ($p = 0.006$) (and A and C) than location D in the non-discarding treatment. Increased pursuit of the constrained green fish could reflect a decreased fear of high point prices of green after the point price change, since they could be discarded, but actual discarding of green is lower in DB than parameter sets B or BD. In the first five periods of parameter set BD, the significantly negative difference between locations B and D (-0.33) offsets the significantly positive interaction with the parameter set primary effect (0.26), leaving little net effect; the probability of selecting B is not distinct from the probability of selecting D in parameter set BD with discarding. In fact, the primary effect of the discarding treatment indicates the probability that picking location B is significantly higher than in the non-discarding treatment ($p = 0.058$).

Table 4 assesses the factors that contribute to discarding each species of fish. It presents estimates from three separate random effects logit models, one for each species, of whether or not

Table 4. Random Effects Logit Models of the Decision to Discard Each Species (when not forced)

	Blue		Green		Red	
Species	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Blue Points	0.30**	0.063	0.04	0.042	0.12**	0.052
Green Points	-0.18**	0.084	0.01	0.053	0.00	0.068
Blue π/point	0.22	0.502	0.43	0.302	1.01**	0.384
Green π/point	-3.67**	1.190	-2.41**	1.069	2.40**	1.028
Red π/point	-0.68**	0.237	-0.29	0.229	-0.58**	0.227
Ln(Points Left)	-0.52**	0.079	-0.33**	0.066	-0.46**	0.073
Set B	-0.11	0.507	1.13**	0.356	1.02**	0.421
Set BD	-0.69	0.614	0.36	0.411	0.02	0.521
Set DB	2.55**	1.113	0.57	0.900	0.45	0.880
Day > 5	0.20	0.494	-0.24	0.333	0.26	0.406
(Day > 5) × B	2.18**	0.880	-0.83	0.600	-1.49**	0.719
(Day > 5) × BD	-0.18	0.695	-1.47**	0.510	-0.90	0.641
(Day > 5) × DB	-2.56**	1.048	-0.78	0.852	-1.17	0.855
Experience	-1.29**	0.641	-1.33**	0.552	-2.77**	0.678
Experience × B	-0.37	0.526	-0.30	0.325	0.00	0.618
Experience × BD	0.21	0.453	1.39**	0.325	1.31**	0.580
Experience × DB	-0.11	0.426	-0.46	0.452	2.08**	0.476
Constant	5.24**	1.210	3.20**	1.037	2.66**	1.115
N	2866		2801		3178	
lnL	-818.38		-1245.97		-1063.48	
Chi-Sq	204.70		273.14		309.59	

Note: ** denotes coefficients with $p < 0.05$, and * denotes $p < 0.10$.

subjects decide to discard at least one pound of their catch of each species. The models focus on strategic discarding, and exclude observations where a subject must discard to have sufficient points to cover her landings. There are two factors that significantly affect all three species: having more points left, as reflected by *Ln*(*points left*), makes subjects significantly less likely to discard; and having experience makes subjects less likely to discard, perhaps reflecting that subjects learn that much of their discarding is unnecessary.

The *Blue Points* and *Green Points* variables are relative normalized point prices (Red Points = 1), and each species' π/point (profit per point) reflects how point prices affect the probability of discarding. Each species has some combination of these variables significant, indicating that subjects are responsive to prices and profit per point, but the relationships are complex and linked through the joint harvest relationships in the locations targeted, making aggregate effects difficult to interpret. That is, it is not feasible for subjects to decide they will discard all non-green fish because the limited days in the fishing season will not allow them to go fishing enough to spend all their points on only green fish; thus they keep some of the other species they catch. Which of the different species are optimal depends on the relative abundance of the different species at the locations they plan to fish. Blue is more likely to be discarded when its point price is high ($p < 10^{-7}$)—a sensible direct effect—but other direct effects are not significant.

Conclusions and Recommendations

Looking across parameter sets, discarding treatments, and experience levels, experimental subjects are broadly responsive to point prices in both their location and discarding decisions. The data are noisy, and there is considerable variation in locations selected—and observations of dominated locations—even in treatments where none is predicted, but there are strong indications that a points system could be used to affect harvester behavior. First, the noise in the data is considerably reduced in the experienced subject sessions, which may more closely reflect behavior in the field where actual harvesters are more familiar with the harvesting options (location, depth, gear, etc.) available in their fisheries than are subjects thrust into a new dynamic environment. Second, despite the noise, the comparative statics predictions of the points system model are supported—when a species' relative point price increases, harvesters change behavior to avoid it—indicating that even inexperienced subjects are responding to the point prices, as well as market prices. Third, even with the somewhat noisy behavior, much of the TAC of each species is harvested, with only modest amounts of overage in all parameter sets and treatments. Collectively, this suggests that a points-based system could be used to effectively manage multispecies fisheries to acceptable biological and economic outcomes.

While subjects are responsive to point prices, there are several practical issues associated with establishing those prices that will be critical to the successful implementation of a points system. The first is what happens when point prices are set incorrectly—a species has its point price set too high or too low—and harvesters respond to those prices, especially if they do so in a dynamically sensitive manner that reflects effort to harvest a species at low point prices before the prices increase. The experimental data in parameter set DB suggest that this does happen: subjects pursue the underpriced species at a greater rate. However, the "derby" observed in the experiment also revealed some of the flexibility of the points system: it did not result in badly exceeding the TAC for the targeted species, or severe underages of other species. The reason for this is that when the points were adjusted, the new prices were able to steer harvesters away from the initially over-harvested fish. Two adjustments took place. First, the point price of the over-harvested fish went up, making it a less good use of points, so harvesters went elsewhere. Second, the price level went up, so harvesters were not able to harvest more fish because they had spent fewer points than expected on the underpriced species. Of course, this sort of flexibility requires that point prices be adjusted at regular enough intervals, and with sufficient precision, that the TAC is not exceeded during the initial derby, or the derby causes profitable joint harvesting to be prohibitively point-intensive.

The second issue is what happens when point prices become an imperfect management instrument because harvesters may avoid the point price cost associated with landing a species because they discard it. Indeed, the experimental results support the hypothesis that point price is a significant driver of the voluntary discarding decision. However, it is more difficult to extend this result directly to the field than it is the others, and thus ascertaining its implications is not straightforward. First, subjects had a fundamentally different relationship with the laboratory fish stock than harvesters do with their stocks; the complexity of the field is impossible to implement in the lab. However, neutrally framing the discarding decision in the lab places an upper bound on the discarding activity observed: in the lab, discarding was a purely economic or strategic decision, and any long-term stock health concerns, moral qualms, or fears of legal or social enforcement that real harvesters might have would attenuate discarding activity. Second, that a positive amount of discarding occurs is not necessarily the appropriate observation, since status quo and other proposed management strategies also have incentives (or explicit requirements) for discarding. The more important question is whether the points system leads to more or less discarding than alternative management systems. The experiments suggest that several factors may affect the decision to discard, including point prices but also the nature of joint harvesting, the relative TACs of jointly harvested species, and whether other species offer greater profit per point.

A final practical issue encountered during the development of this experiment—and which may be prohibitive for a points system—is how to determine adjusted prices in the field. The responsiveness of subjects to the point prices indicates that not just stock levels, but also economic factors (i.e., profitability) must be considered in assessing the attractiveness of different species, and thus stock levels alone cannot determine point prices. In addition, the joint harvesting relationships among stocks mean that stocks cannot necessarily be considered independently. The limited number of harvest locations inspired the discrete approach taken by the price adjustment algorithm developed for the experiment. To the extent that this accurately characterizes the fishery, a discrete approach could be adopted for the field, though it may be prohibitive to characterize all harvest combinations and perform an optimization among them. This suggests adopting a differential tatonnement approach, and it may be that there is sufficient heterogeneity in available locations and vessels within the whole fishery to generate a behavioral response to any modest change in point prices. However, managers should be cautioned that if a differential approach is adopted, but there are in fact a small number of distinct harvesting strategies, then small price changes may not induce any change in behavior, and without a high level of information about the businesses and their harvest strategies, it may be difficult to determine the level of point price change necessary to induce the desired shift in effort across species.

The "derby treatment" of the experiment indicates that harvesters will respond to incorrect point prices; it also suggests that the system can be robust to them, *if* it can make compensating point price adjustments in time. This means that it may be possible to achieve management goals with an imperfect pricing algorithm. What "in time" means varies with the TAC levels and degree of joint harvesting associated with the mispriced stock, but for a fishery with several severely depressed stocks, it is likely to be more than a few times a season; the guiding principle is to be able to correct prices before the derby badly constrains future joint harvesting with the mispriced species.

While this study was being conducted, another management system emerged as a leading contender in the New England Fishery Management Council. In this system—sector allocation—harvesters would be allowed to form voluntary membership groups, or sectors, that would be responsible for managing the members' collective quota allocation, which is based on each members' landings history and days-at-sea allocation. These sectors would have considerable flexibility in managing their quota allocations, and it is likely that different sectors would emerge around different preferred management systems of the member harvesters. Such a sector might be the most sensible venue for implementing a version of the points system. The sector would be exempt from regulation change notification limits that would constrain how often point prices could be updated if the points system were to be adopted fishery-wide, and thus a sector could regularly adjust point prices, compensating for what is likely to be an imperfect point price adjustment algorithm. Further, a sector might have better information about its harvesters' harvest options, and thus be able to better predict responses to point price changes, and have better social monitoring and sanctioning mechanisms to limit discarding. While some of the challenges associated with understanding the joint harvesting relationships and adjusting point prices would still need to be addressed, a points system may be feasible in such an environment.

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