A COMPREHENSIVE BYCATCH MARKET:

INVESTIGATING PRICING MECHANISMS FOR ECOSYSTEM ACCOUNTABILITY

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Abstract:

This report takes an ecosystem approach to managing targeted and non-targeted species in the Bering Sea Aleutian Island commercial fisheries. The current regulatory environment sets biological harvest limits across fish stock's entire range, although the individual components of managing fisheries within a stock may lead to economic inefficiencies and difficulties in accounting for social costs due to blunt incentives. The research presented here outlines a model for scenario analysis and pricing mechanisms at each level of harvest across a species range. Due to the modeled indifference of harvesting in targeted or non-targeted fisheries, designations are made for degrees of ownership rights and monetary transfers to balance these rights in the presence of non-target bycatch. This report argues that efficiency gains can be made by managing behavior through pricing incentives at the margin.

Table of Contents

1. Background

Very few years ago the generally accepted truth was that overfishing would lead to a global collapse in fish stocks (Worm, et al., 2006), and while there is still grave concern for stocks in the developing world, effective management regimes have all but erased concern in the developed world (NOAA Fisheries). The remaining problems in US Fisheries Management are largely not biological, but social. In large part, both the biological protections and social strain are caused by privatization of fisheries resources. Enforceable property rights have been well documented by Coase (1960) and others as an effective means of allocating resources where they are most valuable, thus creating economic efficiencies as well as incentives to protect, or at least manage, resources in the presence of variable abundance fish stocks. Privatization of fisheries resources also creates an inherent conflict as that resource was allocated to all the people in the Alaska State Constitution (1956), and 16 other State Constitutions (National Conference of State Legislatures); although as described by Hardin (1968) and others, open access results in strains to limited resources.

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) (1976) was passed by congress to address resource allocation issues, domestic ownership and States rights (reauthorized 1996, 2015*), whereby the framework for managing the complexities of US fisheries created the Regional Fisheries Management Councils (NOAA, National Marine Fisheries Management). The North Pacific Fisheries Management Council (NPFMC) defines regulations for allocating fisheries resources between various user groups representing harvesters, using small to large vessels and multiple gear types, processing and support sectors, individuals, communities, cultures, and states, as well as providing ecological protections for overlapping stocks reliant on a healthy marine ecosystem. This process requires regulating thousands of individual inputs, to extract billions of pounds of marine resources, and protections for tens-of-billions of pounds of variable abundant and variable recruitment populations over 900,000 square miles covering Alaska's Exclusive Economic Zone – annually. This creates one of the most complex ecological and social systems to manage in the world.

Amazingly successful, the Council system, specifically the NPFMC, in less than 40 years has identified a model for balancing ecological and economic efficiencies through the privatization of rights; the process of getting to this point has been the impetus for epic debate between user groups to determine who receive initial allocation. "The fishery management dilemma is illustrated with a simple stock production curve showing sustainable yield varying with effort. Low effort reduces biological risks and enhances economic profits at the cost of low employment and higher management costs. High effort increases employment at the cost of low economic profits and increased biological and social risks, but with low management costs" (Beddington, Agnew, & Clark, 2007). This process has not been without winners and losers, resulting in underlying tensions between groups that fight to maintain rights. The current debate is complicated by access for future users and social stability of groups that have relied on open access to stocks before resource pressures lead to the current system. While the tension over future access persists, protecting current allocations is complicated by the harvest of non-target species due to overlapping stocks. In some regards, nearly all directed harvesters experience a degree of bycatch. Bycatch, the harvest of non-target species distorts and complicates designing a sustainable long-term model for biological and economic exploitation of marine systems more than any other variable, and may be the single largest issue in managing overlapping marine resources. Bycatch is not unmanageable, but simply a negative externality for which social costs have not been fully accounted, creating incentive systems that are misplaced, hindering the ability of the system to derive maximum efficiency from our marine resources.

This project focuses on the Bering Sea Aleutian Island (BSAI) management area within the NPFMC district, which is specifically selected as to limit project scope to relatively few fisheries that are largely organized into an Individual Transferable Quota (quota) system, with a relatively small domestic population in the affected area. Within the current quota framework, defined management regimes separate each directed fishery, including incentives to reduce bycatch. Data is readily available to determine allocations and payment systems to intended *owners* of the harvested resource. The disjointed management of any one species across multiple gear types of target and non-target stocks is limited to an overall Allowable Biological Catch (ABC), but incentives systems that maintain these boundaries are overlaid on fish stocks in a patchwork of independently managed fisheries. The missing component is individual harvest incentives, both negative for harvest of non-target species, and positive for owners of the directed harvest resource, based on an increasing rate function to account for scarcity of non-target harvest.

2. Ecosystem Based Management

Effective fisheries management is nearly always hindered by uncertainty in the size, composition and spatial distribution of stocks, uncertainty in stock dynamics, stochastic and unpredictable variation in growth of the fish stock, error in implementation of management prescriptions, and variations in economic parameters such as costs and prices that effect optimal management. This can be particularly problematic for rebuilding fisheries for which managers must balance the need to reduce catches to ensure rebuilding, with the need to meet social and economic needs of fishery stakeholders in the short term as well as the long term (Holland, 2010). "A core challenge in diagnosing why some Social-Ecological Systems are sustainable whereas others collapse is the identification and analysis of relationships among multiple levels of these complex systems at different spatial and temporal scales. Understanding a complex whole requires knowledge about specific variables and how their component parts are related. Thus, we must learn how to dissect and harness complexity, rather than eliminate it from such systems" (Ostrom, 2009). At issue with the BSAI ecosystem is not a concern of collapse, rather that the component parts, specifically pricing mechanisms of the comprehensive system are disjointed. Ostrom goes on to tell us that when expected benefits of managing a resource exceed the perceived costs of investing in better rules and norms for most users and their leaders, the probability of users' self-organizing is high. However changing existing systems is not necessarily without cost, so scarcity needs to be evident. The current policy disputes surrounding non-target bycatch, at a time of low abundance and highly valuable stocks is likely pushing change through the NPFMC in the short term (North Pacific Fisheries Management Council). This urgency precipitates and validates the need to investigate a comprehensive bycatch market.

"The past decade has seen a gradual evolution in fisheries management from a primary focus on sustainability of target species and resources to a much wider focus on ecosystems, and the impacts of fisheries on them. This new approach has come to be called ecosystem-based fisheries management (EBFM), or alternatively the ecosystem approach to fisheries. EBFM has increased the scope of fisheries management. In particular, the ecological focus has broadened from concerns about target species and resources to concerns about non-target species, including protected species, habitats, and ecological communities - broadly, to ecosystems." (Smith, Fulton, Hobday, Smigh, & Shoulder, 2007).

Management Strategy Evaluation (MSE) is a general framework aimed at designing and testing Management Procedures (MP) which specify decision rules (heuristics) for setting and adjusting Total Allowable Catch (TAC) or effort levels to achieve fishery management objectives in the presence of modeled assumptions about the dynamics of the resource (Cooke, 1999). Simulation testing is used to determine the extent to which MPs are robust to uncertainty, and MPs are usually selected so that there is a reasonable likelihood that the (pre-specified and quantified) management goals can be satisfied (De Oliveira, Kell, Punt, Roel, & Butterworth, 2008). MPs are elaborate EBFM harvest control rules (HCR) that specify data and assessment methods for determining how the TAC is calculated. A prototypical MSE incorporates a number of interlinked model structures including: population dynamics, data collection, data analysis and stock assessment. An operating model is typically used to generate true ecosystem dynamics including the natural variations in the system. A primary goal of the MSE approach is to assess the performance of different rules in balancing multiple and sometimes competing objectives. Bioeconomic models that often work well in this regard, particularly those designed to identify the optimal harvest strategy, often tend to focus on maximization of profits or fishery rents rather than trying to identify management strategies that balance alternative and sometimes competing objectives such as low biological risk, low variability of catch, and high profits. Ideally this should involve all participants in the fishery. Using MPs to adjust catch of effort levels using pre-agreed decision rules can be more transparent and appear more fair to stakeholders than the traditional management under which scientists produce harvest recommendations from complex stock assessments that stakeholders typically do not understand and have not been involved in. MSEs ideally include, as part of the suite of connected models, an implementation model that allows for a divergence in the desired level of catch and the actual catch. This is likely to be affected by fishing behavior driven by economic considerations and responses to regulation. Implementation models that account for behavioral responses to the economic incentives created by regulations, input and output prices and biological and physical characteristics of the fishery may be better able to predict how future catches will compare to target. Most MSEs could be improved with inclusion of integrated economic models that track economic performance indicators such as costs and revenues and their variability along with biological outcomes. Economists may also be able to suggest and test MPs that create incentives for fisheries to use or reveal private information, which can improve fishery performance in the face of uncertainty. (Holland, 2010)

Taking the ecosystem approach requires simplifying very complex process into a high-level, from where components can to be compartmentalized and dealt with in manageable pieces. Beddington et al (2007) argue that understanding of the fishery management process can only come from analyzing the capacity and incentives of the two key stakeholders: the fishing community and the management authority. Effective incentives need to be allocated at the margin, such that harvesters incorporate the total cost and value of each pound and managers have the ability to apply appropriate pricing mechanisms to incorporate total social costs per unit. Adjusting for social cost requires a comprehensive ecosystem approach, like an MSE model, to understand long-term risk and economic returns, with the ability to dynamically make adjustments as input variables change. Pricing risks and returns should include set aside biomass necessary for future survival of the species, ecological effects on interrelated marine ecosystems, science to appropriately manage for long-term maximum return, and the value of each fish encountered, intentional or otherwise, to the final resource owner. The bycatch price will incorporate total market considerations necessary for reaching a dynamic pricing system for each fish encountered, and total value to the resource owner. Assuming efficient pricing theory, combining the bycatch price and the market price for each fish will represent all variables leading to the total social price per unit at scarcity.

Existing incentive plans do account for the external cost of bycatch, in the form of HCRs (harvest control rules) and hard TACs (total allowable catch) by directed fishery, where aggregate harvest stays below Allowable Biological Catch (ABC); however a working MSE cannot be implemented within the this framework. The existing disjointed system does a fairly good job of accounting for the total ecosystem costs, although blunt tools in the form of hard caps, and fishery closures do not allow for easily implementable MPs to alter marginal behavior in the presence of dynamic stock variance. While analyzing the management costs of allocating individual fish stocks between user groups is outside the scope of this project, this model assumes that carving out hard caps from targeted fisheries increases cost due to the complexity of individually managed fisheries, and neither allows for mechanisms flexible enough to react to ecosystem level changes. This project will identify a framework for creating a comprehensive bycatch model for addressing biological, economic and social externalities, and to form linkages in currently disjointed fisheries (stock and gear type) in the harvest sector of the BSAI region through dynamic pricing schemes consistent across fish stocks, regardless of where or how they are harvested.

3. Incentives for Marginally Induced Behavior

Based on empirical examples, individual management regimes, especially those that leverage marginal behavior can be effective tools for reducing unwanted externalities, namely reduced harvest of non-target species. In 2011, the Pacific Management Council instituted individual bycatch quotas for halibut mortality within the IFQ groundfish trawl fisheries. The resulting decrease in halibut bycatch mortality fell from approximately 0.399 Mlb in 2010 to approximately 0.071 Mlb in 2014, an 82% aggregate reduction (Stewart, Leaman, & Martell, 2015).

In order to determine a cost-benefit ratio, both benefits and costs must be defined within the same framework, which is provided within the National Standards outlined in Magnuson–Stevens Fishery Conservation and Management Act (MSA). Within this framework, cost-effective refers to the lowest social cost method of reducing bycatch, balancing separate directed fishers and their overall economic and social costs of both intrinsic and extrinsic economic, social and environmental costs. At very low levels of bycatch, most of the fishing mortality of the species taken as bycatch is accounted for by other uses and the value of some of the other uses probably are quite low; therefore, the opportunity cost of bycatch and the marginal benefit of reducing bycatch are low. However, at very high levels of bycatch, much of the fishing mortality is accounted for as bycatch, and therefore, the opportunity cost of bycatch and the marginal benefit of reducing bycatch are high. Eventually however, increasingly difficult and often very costly methods would be necessary to eliminate bycatch. Ultimately, low levels of bycatch have a low social cost, which increases with strain on the resource (National Marine Fisheries Service, 1996). Economic theory tells us that the equilibrium should balance where MC=MB. This provides us with the structure for which to price, or tax bycatch. What is missing from the simple scenario is balancing the dynamic and difficult to define externalities.

As outlined by the National Marine Fisheries Service (1996), excessive bycatch is the result of the following set of circumstances: 1) the level of bycatch and the methods used to reduce bycatch are determined by individual fishermen in response to a variety of incentives and constraints that reflect the economic, social, regulatory, biological, and physical environments in which they operate, 2) an individual fisherman will tend to control bycatch up to the point where further changes would increase cost more than benefit, 3) a fisherman will define cost-effective methods of reducing bycatch in terms of the costs paid, 4) the fisherman's benefit from reducing bycatch is less than society's; and 5) when the fisherman's cost of reducing bycatch is greater than society's. These circumstances result in individual fisherman making inadequate and inefficient efforts to control bycatch. Due to the existence of external benefits and costs, individual fishermen receive the wrong signals or incentives and make poor societal decisions, while at the same time making very rational personal decisions. External effects arise when individual's cost-benefit ratios do not equal those perceived by society. Based on this framework, the following conclusions can be reached: 1) for society, the optimum level of bycatch is not zero unless the benefit of eliminating the last unit of bycatch equals or exceeds the cost, 2) individual fishermen make inappropriate decisions concerning bycatch because they do not pay for the opportunity cost of using fish as bycatch, 3) the contribution of commercial fisheries to the well-being of the Nation is decreased further by focusing on a narrow set of alternative uses and ignoring the importance of the distribution of fishing mortality among other uses, 4) physical measures of bycatch are of limited use in comparing the magnitude of the bycatch problem among fisheries because neither the benefit nor the cost of reducing bycatch is the same for all species or even for all fish of the same species, 5) bycatch is a multispecies problem because actions to decrease the bycatch of one species can increase or decrease the bycatch of other species and because the bycatch of one species can affect the status of other species through predator, prey, or other biological interactions, and 6) it is highly unlikely that the use of management measures that limit the choices of fishermen rather than eliminate the externalities will result in cost-effective reductions in bycatch to the optimum levels. (National Marine Fisheries Service, 1996). Due to the negative social cost of unintended harvest, the marginal social cost will always be above the marginal private cost (MSC>MPC), however the problem is exacerbated if incentives are not appropriately assigned, and the ineffective private attempts to address the externality will raise the social costs higher than they would otherwise be.

Hard caps, or Total Allowable Catch (TAC) effectively creates a control rule that limits excessive harvest above the Allowable Biological Catch (ABC) necessary to preserve the species, although this pooled incentive does not create the necessary individual incentives to produce efficient or desired effect. Moral hazard sets in as individual fishermen would incur grater marginal private cost, than marginal social benefit to the pool; quota will become useless when the hard cap is reached so vessels will speed up fishing to ensure that quota is fished, or incur cost of behaving better. However, individual bycatch accountability can be built into the hard cap to induce behavior, thereby eliminating the race for fish as users could balance their external bycatch with the desired individual maximization of target harvest. Rather than a regulation that tells fishermen how to reduce bycatch, the regulatory environment is best served by building the scientific framework for protecting the resource and letting users determine the efficient means of getting there, with limited rather than extensive regulation. In order for these incentives to work appropriately, towards maximizing social benefit, a dynamic incentive structure must emerge (Spraggo, 1998). Both tradable bycatch and increasing tax functions have this effect by assigning a value to resource scarcity.

Externalities are common in the exploitation of marine resources because property rights are seldom fully assigned. Even in the presence of assumed ownership, fish stocks overlap, such that owners do not own everything that is harvested. Boyce (1996) concludes that the introduction of ITQs can eliminate the problems created by bycatch externalities as long as both target and bycatch species are harvested under an ITQ system and the bycatch species does not have an existence value. (Wachsman, 2002). A quota system is a market-based regulation, rather than a "command and control" system, putting the decision about what area to control in the hands of a regulator, the decision to avoid bycatch is put in the hands of every individual making the tradeoff of fishing benefits and all bycatch costs. This means that vessels can choose whatever means of bycatch reduction they see fit, be it avoiding hotspots, fishing more intensively in different times of the year, or using salmon excluders or other alternative fishing technologies that might reduce bycatch (Haynie, 2008).

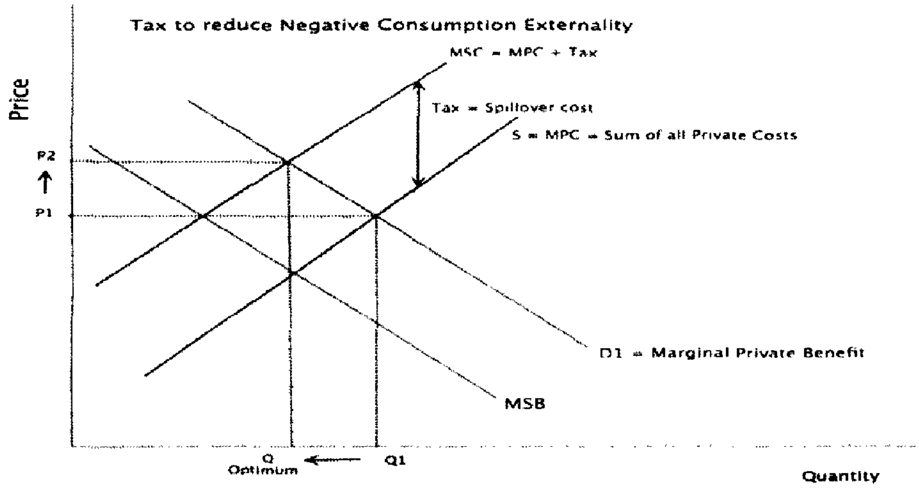
As outlined in (Stavins, 2001), market-based instruments have the potential to provide powerful incentives for companies to adopt cheaper and better pollution (bycatch) alternatives. This is because with market-based instruments, particularly taxes, it always pays firms to operate a bit more efficiently given availability of technology or process to do so. A challenge with charge systems is identifying the appropriate tax rate, as policy makers are more likely to think in terms of a desired level of cleanup, and they do not know beforehand how firms will respond to a given level of taxation. In regard to flexibility, it is important that market-based instruments should be designed to allow for a broad set of compliance alternatives, in terms of both timing and technological options. Melstrom (2014) argues the optimal management strategy is dynamic fishing effort balancing total ecosystem returns. His work shows that management of multi stock fisheries exploited with imperfect selectivity should be managed for the long-run social and ecosystem benefit, which means an annual static objective based on one stock variable is insufficient. As one sector reduces exploitation of the resource, the other sector winds up its harvests. A cyclical harvest policy is optimal because it is difficult to separate the ecological spillover from the targeted stock-effect with changes in the harvest levels. While Melstrom's work is tangential to the *need* for incentive-based management, such flexibility could not be incorporated into a command and control management regime, thus strengthening the argument for flexible incentives that can be tweaked when conditions dictate different behavior is necessary for maximum sustained yield. When designing bycatch reduction policies, the stochastic nature of the problem must be understood. In addition fishermen's ability to avoid bycatch, the actual level of bycatch is affected by random factors like weather, water temperature, joint distribution of the target and the bycatch species in the ocean, time of day and others unknown, which are beyond the control of both the regulator and the fishermen.

4. An Economic Model for Bycatch Utilization

The dynamic state of economic, biologic and social change inherent in the fishing industry precipitates that assumptions and simplifications must control for inputs to focus on one target and one non-target species, in order to monitor marginal change. However, this simplified model can make assumptions that incorporate what change is expected in the natural environment, and how agents will react under different scenarios. Experiments of actual human behavior aim to address effective management of fisheries resources in the presence of negative externalities by establishing a framework for dealing with negative externalities and increasing the efficiency of Alaska's commercially harvested marine resources. The experimental effort will induce efficient choices if the marginal penalty imposed equals the marginal damage caused by their production activities. This simple solution can be assumed because the damage function is modeled to be linear. If interactions are stochastic, then with a non-linear damage function, a tax rate equal to the marginal damage would imply that the tax rate must be random to induce efficient behavior. Specifically, it would depend on the covariance between the marginal damage and the marginal impact of the fisher's avoidance activity (Mukherjee, 2010).

Sutter et al (2006) develop a model to empirically test standard theory of social good. The results from these experimental studies show that highly efficient outcomes can be produced with a per-unit tax on ambient pollution, in this case bycatch, achieving socially acceptable balance in the presence of private externality. This result is robust to the specific tax threshold that is chosen and the nature of communication that occurs.

Chart 1: Balancing Private and Social Cost



https://sangecon.files.wordpress.com/2010/03/g12.png

Based on the model they develop, the desired level of bycatch, B: with total fishery tax on Bycatch:

$$B = \sum_{i=1}^{n} C(t_i) \; ; \qquad C(t_i) = \sum_{i=1}^{n} t_i \; ;$$

Bycatch in absence of tax = γ.

Thus, social benefit is maximized as shown by the Lagrangian method:

$$\text{Min} \sum_{i=1}^{n} C(t_i) \qquad \text{S.T.} \sum_{i=1}^{n} (\gamma - t_i) \leq B^S, \qquad t_i \geq 0, \qquad B_i \geq 0 \; ;$$

$$£ = -\sum_{i=1}^{n} C(t_i) + \lambda\left(B^S - \sum_{i=1}^{n} (\gamma - t_i)\right);$$

The First Order Conditions tell us λ can be interpreted as the marginal benefit of relaxing the socially desired total bycatch, B^S by one unit.

$$\lambda^* = C'(t_i^*);$$

And thus the optimal tax is set to the desired bycatch level divided by participants or Nash Equilibrium:

$$t^{*} = \gamma - B^{s}/_{n} \; ;$$

Sutter et al (2006) explain in many complicated experimental settings it takes many decision periods, and substantial learning, before theoretically optimal outcomes are achieved (if they are achieved at all). In that regard, it is important to investigate the evolution of decisions over time. Ultimately, optimal tax is equal to the price that balances social costs, which are dynamic functions of abundance and value, objective and subjective, over time.

The model developed by Herrera (2004) investigates further the performance of varying fee structures and harvesters response, which through experimental observations is able to make recommendations on optimal regulatory policy. Two species population X and Y, with growth rates (r), harvest withdraw (W) and carrying capacity (K):

$$X_{t+1} = X_t + r_x X_t (1 - X_t/_{K_t}) - W_{X_t}), \qquad Y_{t+1} = Y_t + r_Y Y_t (1 - Y_t/_{K_t}) - W_{Y_t})$$

The withdraw rate of Fleet 1 (W_1) harvests target (X) and non-target (Y) species, given effort (*e*) as a function of catchability (*q*), and bycatch variance (ϑ), for each trip (*j*) at time (*t*):

$$W_{1X_{jt}} = X_t q_{1X^{e_{1,jt}}} \qquad W_{1Y_{jt}} = Y_t \vartheta_{1jt} q_{1Y^{e_{1,jt}}} \; ;$$

And withdraw rate of Fleet 2 (W_2) harvests only species Y:

$$W_{2Yjt} = Y_t q_{2Y^{e_{2,jt}}} ;$$

Total Withdrawals over a given time period (*t*) for species X and Y are:

$$W_{1X} = W_{1Xt} \qquad \& \qquad W_{Yt} = W_{1Yt} + W_{2Yt}$$

Revenue function for Fleet 1, (W_1), with parameter γ represents the reduced intrinsic value of non-target species.

$$TR_{1jt} = P_x R_{1xjt} + (1-\gamma) P_y R_{1Yjt} \; ;$$

Revenue function for Fleet 2, W_2:

$$TR_{2jt} = P_y R_{2jt}$$

In the model provided here, regulatory policy can alter the ex-vessel benefits of harvesting X and Y, such as a per-unit tax on non-target species Y. Independent of additional taxes, the realization of bycatch parameter ϑ is known to harvesters only after reaching the fishing grounds, once fixed costs associated with a trip have been incurred. A trip is taken only if expected profits are positive. Given the regulator imposes a per-unit tax (τ). The harvester strives to maximize profit (assume no discards), but aborts fishing if MC>MR, after assuming variable costs a function of effort (ce_{jt}) and fixed costs (FC). Taking account of tax effect into the profit function in the presence of bycatch:

$$\Pi_{jt} = P_x(q_{X^{e_{jt}}} X_t) + \{((1-\gamma)P_y - \tau_{jt}) q_{Y^{e_{jt}}} Y_t \vartheta\} - ce_{jt} - FC$$

Herrera's model supports the dynamic and unforeseeable variables related to pricing unintended consequences of non-target harvest, and further supports the model with empirical experimental data identifying the efficiency of fee based policy for matching private costs to social benefit. Specifically, adjusting the tax has a substantial effect on marginal behavior, and is thus a superior policy tool regarding its efficiency to elicit marginally desired response.

5. Analysis of Pricing Efficiency

Most bioeconomic models consider only the marginal cost of harvest effort, although fixed costs are likely to play an important factor into behavior of capital intensive fisheries. It is important to note the relative advantage of a tax system over the other policies, as incremental fees grow and contribute to overall operating costs, making implementation of a price instrument more cost-effective. In addition to efficiency, fee based policy is easily adjusted on the margin. This becomes critical in the presence of stochastic abundance of overlapping species complexes, especially in rich ecosystems with a high degree of productivity. When the bycatch level is uncertain, the incentive structure must be flexible.

A major encumbrance in defining the optimal efficiency framework, are laws requiring discarding non-target harvest. Discard policy is not based on efficiency, and is more likely aimed at reducing incentives for retaining bycatch. Unfortunately, the resulting mortality represents an enormous lost value to society. Furthermore, implementing a tax on non-target harvest would prove politically challenging given the entitlement of bycatch as a historical component of production in the target fishery. However, if managers hope to address the production externalities associated with multi-complex fisheries, market incentives are critical, as incentives for a new regulatory environment, appropriate behavior and optimization of limited natural resources (Boyce, 1996).

Bisack and Sutinen's (2006) research suggest that there may be efficiency gains associated with providing resource rights to harvesters of non-target species. Hayne, Hicks and Schnier (2008) find the existing regulatory environment in the BSAI groundfish fishery provides only loose ownership of bycatch, even as some bycatch is regarded as essential to harvest in the directed fishery. Hard caps in the presence of a rationalized fishery do instill ownership rights, as the 22 groundfish fishing vessels must ensure the hard caps are not reached, triggering a shutdown. This quasi ownership results in interesting behavior, as bycatch is avoided to a high degree, relative to the day-to-day rates, based on the total level of bycatch remaining. In an effort to maximize allocation of bycatch, fishermen reduce their degree of aversion as the season progresses, catching higher rates of bycatch and approaching the hard cap by the end of the season. In such a system, economic efficiency still rests on the degree of fleet cooperation and not direct market mechanisms. This infers that fishermen do have an ability to reduce bycatch. Given the current regulatory regime, complete efficiency is unlikely to be obtained unless fishermen participating in the flatfish fisheries are allowed to have ownership rights to bycatch (Haynie, Hicks, & Schnier, 2008).

At the individual gear-deployment level catch composition varies greatly based on spatial and temporal deployment, indicating that fishermen have the ability to significant avoid bycatch, which is behavioral in nature rather than purely technical. When it becomes clear that fishermen have sufficient halibut quota remaining to avoid premature closure of the fishery, they relax their avoidance measures and bycatch ratios increase. This creates the potential for management policy to exert some degree of control over this aspect of fishing through its influence on the incentives faced by fishermen. Abbot, Haynie and Reimer (2015) find that under a new management structure, with individual incentives under a multispecies catch share system, with individual accountability for their catch of target and bycatch species, dramatic evidence of a shift in overall catch composition away from bycatch species and toward valuable target species as well as far less variability in the target/bycatch ratio. Importantly, these margins of change were all available to fishermen before the institutional change and yet were not adopted. This suggests that management systems which provide few incentives for selective fishing may obscure fishermen's ability to alter their catch composition. New incentives can induce a wide variety of significant changes in fishing behavior.

By providing fishermen strong individual incentives for bycatch avoidance, (MSA) Amendment 80 drove fishermen to exploit previously underutilized substitution possibilities in their daily allocation of fishing time to reduce their bycatch. It is notable that these margins involved changes in the behavior of fishing decision-makers rather than the adoption of new gear. It was not until vessels faced individual bycatch constraints that vessel operators found it in their interest to utilize the new technology, despite its widespread availability. To do otherwise would have meant bearing the full cost of lost target catch and the direct cost and inconvenience of the gear modification itself while receiving only a small fraction of the benefits (Abbott, Haynie, & Reimer, 2015).

In *Use of incentive based management systems to limit bycatch and discarding,* Pascoe, et al. (2010) outline key elements of designing appropriate regulatory frameworks for addressing fishing behavior. Pricing bycatch appropriately provides incentives for fishers to adjust their production and fishing effort to account for additional costs, and provides an incentive for fishers to adopt technologies that reduce these costs through reducing bycatch. Fishers are able to explicitly balance the benefits of fishing in a given area or time period against the costs of fishing, including the cost associated with bycatch. An advantage of such a tax system is that, theoretically, different species can attract different tax rates thereby ensuring the greatest protection to the most vulnerable species. The potential benefits of a bycatch tax in reducing the level of bycatch have been demonstrated by a number of authors ((Jensen & Vestergaard, 2002) (Sanchirico, 2003) (Diamond, 2004) (Herrera, 2004) (Singh & Weninger, 2009)).

New Zealand's ITQ management system includes species of limited value that were previously considered bycatch. This effectively creates a system of individual bycatch quotas and, through the deemed value system, a bycatch tax. The deemed value approach allows fishers to land and sell quota in excess of the Allowable Catch Entitlement (ACE), but pay a fee, varying by species and stocks. The effective price received for the fish is then the market value less the deemed value. In addition, since the annual level of the deemed value charged to the fisher increases as over-quota catch increases. The actual level of the penalty is a key determinant of the effectiveness of the system ((Marchal, Lallemand, Stokes, & Thébaud, 2009). The deemed value system gives managers considerable flexibility to *tune* the incentive structure to the particular circumstances of a fishery. Not only can managers adjust the basic deemed value rate, they can also adjust the rate at which it increases for increasing levels of catch in excess ACE. The increasing level of disincentive for larger amounts of over-harvest reflects resource limitations. Thus the regime provides flexibility to all fishing operations to cope with the unpredictability inherent in mixed-species fisheries and strong incentives for fishers to avoid fish for which no ACE can be obtained. By all accounts this regime provides New Zealand with strong and flexible incentives with which to significantly improve the management of multi-species fisheries (Peacey, 2002).

6. Comprehensive Bycatch Tax

While the ownership of individual stocks for harvest remains very important, Ecosystem Based Fisheries Management (EBFM) provides the framework to consider fish stocks across their entire range, regardless of where or by who they are harvested. With the assumption that all fisheries encounter some degree of bycatch, preserving or identifying ownership is crucial for a comprehensive model, where fees are paid to those owners in compensation for non-owners inadvertently using the resource. Preempting enforceable property rights is the assumption that a consistent set of rules applies to all user groups, regarding their requirement to pay for harvest of non-target species. The current system does not allow rents for total resource ownership, nor does it provide ownership rights for inadvertent bycatch harvest. Essentially, market mechanisms are not in place to allocate value to non-target bycatch species, nor do they indicate lost value on behalf of the directed resource owner. This lack of clarity has allowed for a misalignment of bycatch incentives. "Conventional bycatch management measures that prematurely close target fisheries when hard bycatch caps are met succeed in conserving bycatch species, at the expense of wasted returns from the target fishery. Measures applied at the fishery-wide level do little, if anything, to generate individual incentives to avoid bycatch" (Wilen, March 2009). Existing markets have already set the base price for each pound of product harvested; the missing component is the externality of non-target species. This model will investigate the variance in ownership structures and degree to which those affect behavior of fisheries exploitation.

Existing resource owners of targeted fisheries, such as Chinook salmon gillnet and halibut hook-and-line fishermen of the Yukon and Bering Sea and Aleutian Islands (BSAI) respectively, are paid a market price for the fish they target, although they also incur the biological, economic and social cost of fish they do not catch. Alternatively, harvesters of non-target bycatch, such as trawl fishermen of the Bering Sea pay the difficult to quantify risk of shutting down their directed fishery in the presence of biological bycatch thresholds; however, they also pay no measurable reparations, nor do they assume any ownership benefit of non-target species, even though there is a historical connection to these species. Resource owners selling product up the value chain (or assumed value of subsistence use), from harvest in the round to value added processing sets the market rate for all species, target and non-target. Setting interim bycatch tax where ownership is not fully accounted for, in the presence of negative externalities is not a static price relative to market price, but dynamic in the presence of economic, but also additional biological and social pressures, and thus need a dynamic adjustable cost function at each unit of harvest.

BSAI fisheries are fully utilized, and thus all targeted stocks include a market price determined by supply and demand mechanism in the targeted fishery, which sets the baseline for non-target stocks across the same species. Setting desirable marginal incentives requires that all non-target bycatch be sold at the market rate; which assumes 100% utilization of the resource. This is not to say that all the benefits from the sale of the resource flows to harvesters of bycatch species; a fee must be established to balance the external cost associated with each level of non-target harvest. That fee should range from $0 to a price necessary to balance social costs. As biological limits are approached, the socially acceptable level would prevent all future fishing, and thus be equivalent to all expected revenue for that vessel trip in the presence of the constrained species, in essence setting a hard cap at the biological limit of the non-target species, as is now the case. Investigating the appropriate bycatch tax is the subject of this analysis.

Identifying the appropriate bycatch tax must be a function of component value, which assume characteristics intrinsic to a particular fish stock. A statistical model, including all points along a production function, represents total range of proposed Bycatch tax. This variable is a function of: 1) quality; 2) abundance; 3) social strain; and 4) degree of ownership:

1) Quality – Harvest of targeted species aim to maximize resource net present value for the derived value of attributes. Non-target species may not maximize quality, as unintended harvest occurs while targeting the directed fishery, and thus bycatch quality is not maximized. Quality in a statistical bycatch pricing model

requires an independent variable representing the deviation of bycatch quality from that of the directed harvest. Parameters determining Quality should be linear.

2) Abundance – Management of the target species incorporates annual abundance, individual growth rate and aggregate rates of replacement, but non-target harvest places pressure on the stock and needs to be priced accordingly. Sustainably managed fisheries incorporate the effect of total stock extraction, so every unit is counted against stock abundance, regardless of fishery. Abundance in a statistical bycatch pricing model requires an independent variable representing the increasing relative pressure on the stock at each unit of harvest. Parameters determining Abundance should exhibit an increasing rate function, representative of limited pressure at low levels, but increasing with strain on the resource, becoming exponential if the Allowable Biological Catch is exceeded.

3) Social Strain – The premium society places on the resource, not included in market price, represents social strain. Oftentimes fishing is not described as a career, but a way of life for traditional users of the resource, especially within coastal or riverine communities. The cultural or social connection in itself is a function of multivariate component parts. Social Strain in a statistical bycatch pricing model requires an independent variable representing the perceived non-market value to resource users. Parameters determining Social Strain may require a linear change, as well as increasing rates of change, depending on circumstance.

4) Degree of Ownership – The current BSAI management system assumes that the owners retain total resource value, but stocks are managed to include targeted and non-targeted fisheries; thus, targeted harvesters do not own 100% of the exploitable stock due to lost bycatch harvest from other directed fisheries. Likewise, non-targeted fisheries assume no ownership, although their proportional catch may include substantial allocation of total stock exploitation, as well as a historical connection to the non-target species. These mechanisms do not incorporate external cost to targeted resource users who do not receive total assumed value, nor do non-target resource users incorporate appropriate incentives to optimize their *ownership* of the resource. Degree of Ownership in a statistical bycatch pricing model requires an independent variable representing proportional resource

ownership. Parameters determining a Degree of Ownership should be developed as a function of abundance and social strain, investigating ownership for non-target harvests at low to medium levels, and some transfer to the directed fishery at medium to high levels of non-target harvest. Ultimately, high degrees of ownership would indicate bycatch fees below market rate, and thus profit for non-target harvest, whereas high degrees of ownership for the targeted fishery would indicate direct transfer for the use of the resource from non-target harvesters.

The statistical bycatch pricing model described here has too many unknown variables to calculate bycatch price without empirical data. It is beyond the scope of this project to fully understand the degree of influence that each variable has on the final bycatch fee. Future studies should incorporate these characteristics into a model to collect and test empirical data through experimental methods. Experimentation has proved an effective tool to test other aspects of tax efficiency, although none of the work has specifically tested bycatch pricing mechanisms in the Alaska market. Given the uncertainty and variance of complex behavior associated with fisheries resources, it is advised that extensive modeled behavior predicates any effort to implement actual policy to value a dynamic bycatch tax.

This research will now investigate the effects of changing price points on the MSE framework necessary to achieve market efficiencies and behavioral changes which produce desirable outcomes.

7. Designing an Optimal Regulatory Environment

Assumptions must be made in designing an optimal regulatory environment given the existing framework. First, there must not be discards of any species; second, a fully functional electronic monitoring systems ensures compliance; third, there is a market price for all species; fourth, the Allowable Biological Catch (ABC) perfectly matches stock abundance; and fifth, stakeholders must identify a need for policy change that is broadly supported. Additional assumptions that while impractical, is necessary to limit complexity of the proposed model for the sake of measuring outcome. First, sales of all harvest products is retained; second, tax revenues are used to balance negative externalities; third, bycatch can be marginally mitigated through avoidance; fourth, regulatory levers can be adjusted quickly in line with biological necessity to affect the desired change; and fifth, regulatory policy is defined for only the Pollack catcher vessel fleet, in regards to halibut and Chinook bycatch. Given the assumptions outlined here, the following recommendation is put forward, for analysis. Implementation of a bycatch tax on halibut and Chinook in the Pollack CV trawl fleet, which is transferred to owners of the directed fishery and increases with strain on the resource, equivalent to actual social costs.

The success or failure of this proposal will weigh heavily on the appropriateness of the increasing cost function of the tax. By one account the marginal tax should be equivalent to the biological bycatch hard-cap, thus the tax should raise until a single unit of bycatch dissuades any further harvest. By this rational, equivalent to the trip value, which for the Pollock CV is about $38,250, (225,000 pounds of Pollack * $0.17 per pound). Given a Chinook hard-cap of 948,438 pounds (60,000 fish) and halibut hard-cap of 7,040,000 (3200 metric tons) we can calculate the straight-line tax increase by dividing the trip value by the bycatch weight. This would have the first pound of Chinook taxed at $0.040 per pound and the first pound of halibut taxed at $0.005, whereby each bycatch pound harvested afterwards would increase by that amount, for each bycatch species.

The shortcoming of setting a the straight line from zero to the trip value is that only 85 pounds ($3.38/$.04) of Chinook and 1,070 pounds ($5.35/$.005) of halibut could be caught fleet-wide before the Pollock fishery began incurring steep fees (market prices of $3.38 for Chinook and $5.35 for halibut as reported in the Bering Sea region by the Alaska Department of Fish and Game, 2013). The model outlined here essentially assumes almost no bycatch ownership for the Pollack fleet. Further, these steep taxes seems draconian and far in excess of what might be considered reasonable in addition to damaging overall social good, as the Pollack resource would surely go underutilized.

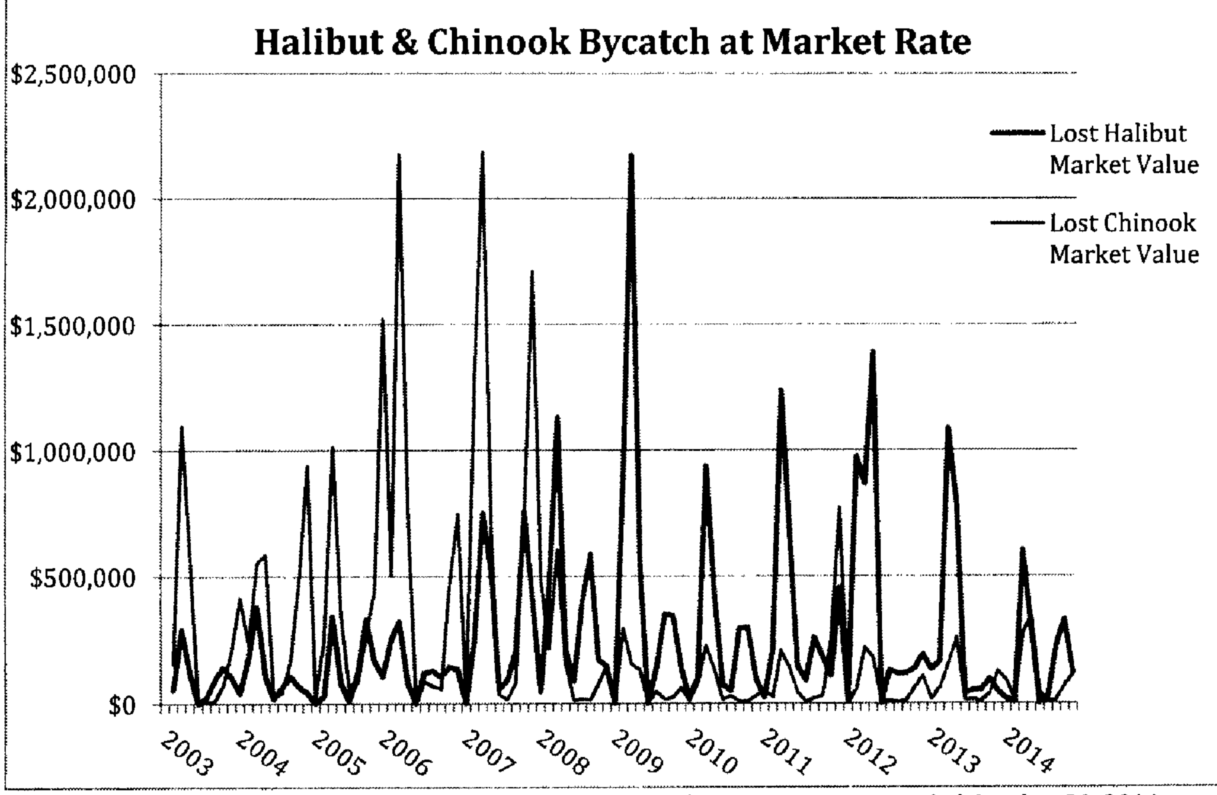
As shown in the New Zealand model, the tax on deemed value raises to two-times the market value of the resource. In this case Chinook and halibut would be priced at two-times value, equal to $6.67 and $10.70 per pound of bycatch respectively. Although in this example, it is reasonable to assume four-time market value given that the Pollack trawl fleet only rarely approaches the hard-cap, setting the tax at $13.52 and $21.24 per pound of Chinook and halibut bycatch respectively. An assumption of two-times and four-times market value is a unit increase or slope of $0.0000071 at two-times market value and $0.0000143 at four-times market value for Chinook and $0.0000015 at two-times market value and $0.0000030 at four-times market value for halibut. See Table 1. More importantly this means that at two-times market value the bycatch earns a profit for the trawl fleet for the first 50% of bycatch ABC, or 474,218 pounds of Chinook and 3,520,000 of halibut. With an assumed tax at four-times market value the trawl fleet profits on only the first 25% of non-target bycatch, or 237,109 pounds of Chinook and 1,760,000 pounds of halibut before tax schedule is equal to the market rate.

Table 1: Bycatch Tax Schedule

Bycatch Species	Allowable Biological Catch	Market Price	2X Market Price	2X Market Rate Increase	4X Market Price	4X Market Rate Increase
Chinook	948,438	$3.38	$6.76	$0.0000071	$13.52	$0.0000143
Halibut	7,040,000	$5.35	$10.70	$0.0000015	$21.40	$0.0000030

The simple pricing charts listed here provides a baseline for investigating mechanisms that could strongly encouraged behavioral nudges supported by managers to improve system-wide efficiency, and/or other biological, social or economic objectives. The power of incremental pricing incentives is that it applies value to each unit for the entire range of stock, so that external or unanticipated behavior is accounted for. Altering positive or negative outcomes becomes a degree of change; however, without empirical data understanding how marginal incentives will affect behavior cannot be well understood.

Chart 2: Foregone Halibut and Chinook Bycatch Value



Josh Keaton, NMFS, emailed October 30, 2014

Applying this model to real catch statistics will help strengthen assumptions about effects on altering behavior and improving social benefit. The starkest statistic is that between 2003-2014, $28 million in Chinook and $29 million in halibut ex-vessel value has been lost due to inefficient use of bycatch resources in the Pollack trawl fishery. Annual foregone value by species, by month is listed in Chart 2. The model proposed here would capture that lost value, splitting the ex-vessel gains between the Pollock fleet and directed Chinook and halibut owners, plus all supply chain components. As proposed the entire value of bycatch sold would be retained within the Pollock fishery, although additional taxes would be taken out and transferred to Chinook and halibut direct fishers. Based on 50% (2X market tax) and 25% (4X market tax) bycatch ownership, the Pollock fleet would retain and transfer values listed in tables 1 & 2, with red text indicating a tax above the market rate.

Table 2: Chinook Value and Tax Rates

	Chinook Salmon Market Value	Chinook 2X Market Tax	Chinook 4X Market Tax	Trawl Bycatch 4X Tax Rate Fee or Subsidy
2003	$2,535,531	$1,796,516	$3,641,515	-$1,105,984
2004	$3,055,300	$2,548,822	$5,166,428	-$2,111,128
2005	$3,978,611	$4,368,037	$8,853,952	-$4,875,341
2006	$4,884,765	$6,701,763	$13,584,383	-$8,699,618
2007	$7,209,696	$14,525,595	$29,443,184	-$22,233,488
2008	$1,260,670	$454,168	$920,592	$340,079
2009	$743,363	$127,627	$258,699	$484,664
2010	$574,931	$92,127	$186,741	$388,190
2011	$1,506,901	$635,038	$1,287,214	$219,687
2012	$670,380	$124,937	$253,246	$417,134
2013	$770,143	$163,429	$331,268	$438,875
2014	$887,221	$218,398	$442,690	$444,531
Cumulative	**$28,077,511.73**	**$31,756,457.35**	**$64,369,910.55**	**$36,292,398.82**

Table 3: Halibut Value and Tax Rates

	Halibut Market Value	Halibut 2X Market Tax	Halibut 4X Market Tax	Trawl Bycatch 4X Tax Rate Fee or Subsidy
2003	$871,390	$21,386	$42,453	$828,938
2004	$962,879	$26,344	$52,295	$910,584
2005	$1,185,670	$39,761	$78,927	$1,106,744
2006	$1,286,961	$46,956	$93,210	$1,193,751
2007	$3,078,870	$266,650	$529,312	$2,549,558
2008	$3,194,336	$291,870	$579,376	$2,614,960
2009	$4,644,492	$814,756	$1,617,329	$3,027,163
2010	$2,309,653	$151,632	$300,998	$2,008,655
2011	$3,395,963	$325,142	$645,422	$2,750,541
2012	$4,052,788	$479,539	$951,908	$3,100,880
2013	$2,345,959	$159,202	$316,024	$2,029,935
2014	$1,600,296	$73,352	$145,607	$1,454,688
Cumulative	**$28,929,257.54**	**$2,696,591.96**	**$5,352,861.05**	**$23,576,396.49**

This simple linear bycatch tax model provides insight into Chinook non-target harvest. Given that the only fees assessed with the two-times market rate tax were incurred in the years 2005-2007 when Chinook bycatch exceeded the 60,000 fish cap, and actually provided a subsidy in all other year, it may appear this tax rate would be set too low. While the four-times market rate tax seems to fit better, there could still be concerns from both non-target and targeted resources users. The targeted users could very well argue that while minimal harvests are occurring, very low levels of abundance in recent years have eliminated the directed harvest of Chinook, so bycatch at any level should be strictly prohibited, let alone provided a (small) subsidy to do so. The transfer of a few hundred thousand dollars to Western Alaska villages may do little to offset the perceived pain of losing a cultural connection to Chinook, and the real pan of empty village freezers. Non-target harvesters could make similar arguments that the large fees assessed between 2005-2007 are excessive, where the reason for high bycatch is stock abundance, and thus fees could be set too high. This simple model assumes that a 60,000 fish upper bounds (ABC) is appropriate at all levels, but adjusting this number drastically changes the fee structure. Changing the upper bounds on Chinook bycatch to 20,000, as is currently being discussed by the NPFMC, shifts heavy fees onto the non-target fleet in every year at the four-times market rate tax, exceeding $115 million in 2007. Similarly, raising the upper bounds on Chinook bycatch to 120,000 fish for high abundance years, would yield a subsidy to the trawl fleet in all years except 2007, where the fee and market sales balance exactly (there were 120,000 Chinook taken as bycatch that year).

The model provided here appears to under-price the fee on halibut bycatch, yielding a subsidy every year to the non-target fleet. Currently, the BSAI halibut fishery is facing a shutdown due to stock concerns, although conclusions should not be made based on the limited data available to base final decisions. Halibut is taken in very limited numbers in the Pollock trawl fishery, and the prices here may reflect a absolute benefit to the trawl fleet, but the transfer to the directed fishery, while limited most years, may be sufficient to balance the social costs of limited halibut bycatch encountered in the Pollack trawl fleet (groundfish fleet is another story).

The degree of ownership will dictate how revenue is generated and distributed from the bycatch market. The current and clearest owners of the bycatch resource are those operating in the target fishery. The degree of ownership for target and non-target species, as well as the increasing rate of bycatch tax should be investigated for economic optimality. Testing increasing costs functions at key junctions, can be modeled and tested through economic experimentation. Running experimentation will also provide empirical data that will help managers better understand how altering the regulatory environment will affect real responses. It is very likely that the components representing the true social cost of fisheries resources will require a more elaborate bycatch pricing model, whereby prices fluctuate to represent dynamic resource strain.

8. Expected Behavior and Insights

This report aims to address the negative externality of non-target bycatch in the presence of a targeted stock, a problem that plagues almost every fishy in Alaska to some degree. Even harvests of target species, are considered non-target under certain circumstances, as identified in the data for the directed halibut fishery for undersized discards, thus behavior identified here may provide useful insights across many fisheries. Controlling for a degree of ownership and the assumed value of both target and non-target species provides powerful behavioral nudges in the presence of pricing mechanisms, and thus proves a useful tool to investigate how an ecosystem perspective might improve resource management. A much more powerful conclusion could be drawn from the aggregation of the entire ecosystem, although that level of complexity would incorporate vast arrays of variables that would prove very difficult to model.

Economically, the directed Pollock fishery could absorb the entire allocation of Chinook salmon, paying more for the product and creating economic efficiency, although the social value of the directed Chinook fishery likely exceeds the strict market value. An important attribute that this model does not capture well is the contingent valuation representing the social and cultural connection to fisheries resources. Fisheries valuations can incorporate social costs into experimentation by adding unaccounted market value - increasing fees, although cultural values are not easily convertible to monitory terms, and risk skewing expected outcomes. It is reasonable to assume that after including subsistence and cultural connection to this generation and future generations {Alaska's supreme court is currently hearing a case defending access to Chinook as a religious right (State v. Ivan, Et Al.)}, real monitory valuations may need to be vastly inflated to accurately capture the true value of directed harvest of iconic species. Other fisheries will carry similar contingent valuations that need to be included when applying a market rate for the directed fishery; this is especially true for small-boat and artisanal fisheries supporting a historically strong community connection to the stock. While money may not accurately represent the intrinsic value of a stock, fishermen should respond appropriately to signals from exponentially higher valuations.

Altering the degree of bycatch ownership will help provide insight into the perceived value of bycatch quota and shed light on the true value of directed fishery to all resource owners. Chinook carry a market premium and are thus valuable to all user groups. To the directed Pollock fishery, there is very little actual cost of harvesting Chinook bycatch, so any allocation they receive for market value will be of interest. From this perspective, balancing social costs of Chinook bycatch in the trawl fishery may yield interesting results. Given the high value and low costs to the Pollock fishery, incentives exist to harvest to economic parity, which is the reason non-retention laws exist. Maybe a more appropriate tax schedule is parity to market value, although without costs for excessive bycatch, the Pollock fleet could easily over-harvest their allocation, so an increasing rate function is likely necessary at some point. Consideration should be given to the absolute costs of non-target harvest such that they may represent a minimal portion of the overall operations costs, and only very high fees would change behavior, assuming avoidance is possible. Also, the economic value of harvesting Chinook in the trawl fishery must be taken into account, which is likely much higher than Western Alaska artisanal fisheries, so some bycatch must be acceptable. Future analysis must go further towards incorporating real scenario planning to make viable assumptions to expected behavior.

9. Conclusion

This project should not be assumed to represent a comprehensive understanding of dynamics between target and non-target species. The current regulatory framework curbs bycatch, in both the Pollock and Chinook fisheries, but also every other fishery where bycatch has been identified in the targeted fishery. Fisheries resources represent a unique place in the Alaska economy, with deep historical and social connections, in addition to Constitutional mandates allocating fish to all the people, although it was long ago understood that without appropriate market mechanisms the resource would be squandered for future generations. All of which needs to be taken into account when identifying policy for managing one of the most complex markets in the world.

What should be learned from this effort is that pricing mechanisms, when applied on an ecosystem level, across the entire range of a stock, could have powerful incentives to promote better-managed and more efficient fisheries. This effort is based on the assumption that implementing incremental nudges to encourage desired responses organically from the collective effort of many independent parts is a more effective means of achieving results than a controlled regulatory environment that attempts to define the entire range of anticipated responses from independent agents, in order to achieve a desired outcome.

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