

Quantitative evaluation of the performance of a permit auction system in reducing bycatch of sea turtles in the Hawaii Swordfish longline fishery

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ABSTRACT

Many authors have suggested the use of a cap and trade auction system to help reduce bycatch—the incidental take of species by fishing gear targeting other species—of sea turtles in the Hawaii-based swordfish longline fishery. However, we know of no quantitative evaluations of the method. We present a simple mathematical model to serve as a framework to evaluate bycatch auction systems quantitatively. We conclude that cap and trade auction systems have the potential to reduce sea turtle bycatch by creating a financial incentive, while keeping permit costs down to 2–3% of total revenues. While stringent regulations aimed at conserving endangered sea turtles would still be essential, implementation of an auction for issuing transferable bycatch permits would likely enhance the economic efficiency of the fleet. Sea turtle mortality could be reduced further if a shrinking cap on total turtle mortality was introduced, taking advantage of the incentives for reducing turtle mortality that are introduced by the cap and trade auction system.

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1. Background

The Hawaii longline swordfish and tuna industry have been plagued by sea turtle bycatch. The industry employs fishing lines, often several kilometers long, which, in addition to catching their intended target species, also catch endangered sea turtles. Regulatory action has so far been primarily focused on limiting bycatch to an annual cap.

The annual cap approach, while limiting the number of turtles killed by the longline fishing industry, creates perverse incentives for fishermen. Since the annual bycatch cap is essentially a common good shared by all fishermen, there is no incentive for individual fishermen to be efficient in avoiding killing turtles. In fact, the optimal strategy for the individual is to maximize catch by ignoring the turtle bycatch issue, since if one tries to avoid catching turtles (at some additional cost), a competitor will simply use up the cap. This incentives can result in a “tragedy of the commons.” During the 2006 season, the Hawaii-based longline fishery was shut down after only 6 weeks to avoid exceeding the turtle bycatch cap.

In this paper, we assess the feasibility of an auction-based system, wherein the individual fishermen would bid for turtle

bycatch permits. In the first year, permits would be allocated free of charge to all participants. This would allow fishermen to assess the potential revenue generated per permit, which in turn would allow them to properly price the permits in the future. After the first year, fishermen would bid for permits. This creates incentives for each fishery to become more efficient, as permit costs would drop if more advanced technologies that target swordfish more effectively and catch fewer turtles were developed and deployed. The auction system could potentially re-align incentives to reward selective and efficient fisheries.

The existing literature in this field has focused on the description of these problems, but proposals for solving the tragedy of the commons in this case are few and quantitative assessments of proposed solutions are even scarcer.

2. Modeling

2.1. Swordfish fishery modeling

We developed a simple model of the Hawaii-based swordfish fishery in order to investigate the effects of a permit auction system.¹

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¹ Code for the model is available from the corresponding authors.

Table 1
Hawaiian longline fishery revenue

Year	Longliner revenue (\$ million)	Tuna-targeted trips	Swordfish-targeted trips	Total trips	Revenue generated per trip
1991	38.7	556	1115	1671	0.0232
1992	40.19	458	808	1266	0.0317
1993	45.44	542	650	1192	0.0381
1994	36.37	568	538	1106	0.0329
1995	36.64	682	443	1125	0.0326
1996	34.25	657	443	1100	0.0311
1997	38.72	745	380	1125	0.0344
1998	38.75	760	380	1140	0.0340
1999	39.69	795	369	1164	0.0341
2000	43.24	840	294	1134	0.0381
				Mean	0.0330
				Standard deviation	0.0042

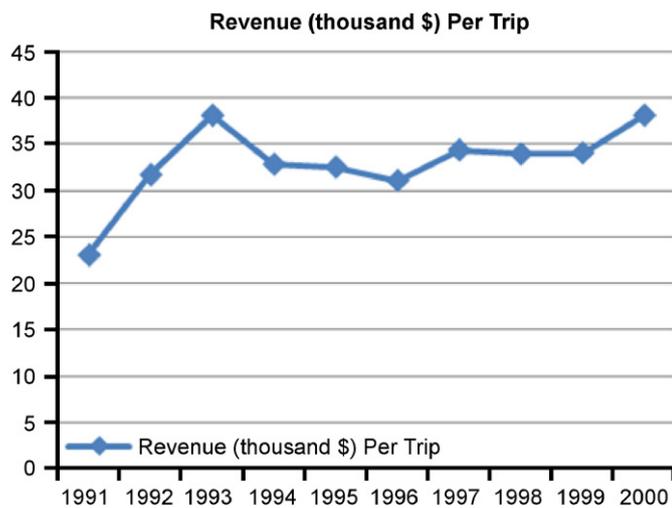


Fig. 1. Hawaii longline fishery revenue.

3. Revenue

Pradhan and Leung [1] provide the basic fishery economic data for the model (Table 1 and Fig. 1).

We assume that tuna-targeted trips and swordfish-targeted trips generate roughly the same amount of revenue per trip. We denote the revenue generated per swordfish-targeted trip by R . We will model the variation in R by assuming that it follows a geometric Brownian motion. This is based on the broadly accepted premise that prices and thus revenue fluctuate according to this type of distribution [2]:

$$\frac{dR}{R} = \mu dt + \sigma dW$$

Variables μ and σ are constants; W is a one-dimensional Brownian Motion parameter.

Using the generalized method of moments (a conventional method for fitting a model to data [3]) we estimate that if we use 2 months as our unit time interval, $\mu = 0.0043$ and $\sigma = 0.02444$.

4. Expenses

Based on the description of the longline fishery by the UN Food and Agriculture Organization [4], we assume that 83% of the revenues are consumed by fishing costs. We introduce random variation to the costs of fishing trips by adding an additional Gaussian white noise term (standard deviation = 5%) whose mean and variance are fixed for our simulations. There are two main

reasons for this: first, we are fixing the revenue generated by a fishing trip during one period (i.e., 2 months); hence, expenses must be allowed to vary randomly to capture the uncertainty of the profits generated by fishing trips. Secondly, this approach allows us to test the stability of our results.

5. Sea turtle encounters

Very little is known about the rarest species of sea turtles in Hawaii. Even basic information on distribution and abundance is lacking. Hence, we have modeled sea turtle encounters in the Hawaii swordfish fishery as events governed by a Poisson process with intensity λ (i.e., in a very short time period dt , the probability of an encounter with a sea turtle is λdt and for periods that do not overlap with each other, the probability of sea turtle encounter is independent). To estimate the value of λ , we minimized the differences between the probabilities of sea turtle encounters generated by the Poisson process and the observed probabilities in Pradhan and Leung [1], essentially employing a non-linear least squares optimization procedure.

6. Fishery composition

According to Pradhan and Leung [1], during the period 1991–2001 there were on average 125 longliners working the swordfish fishery off Hawaii. Here we assume that 125 longliners in total participate in the fishery, and that they are owned by five fishing firms. We further assume that each of the five organizations owns 25 longliners.

7. Characterization of fishing technologies

The specific fishing technology that a swordfish longliner uses has a strong impact on the number of turtles it catches during a trip and on the likelihood of turtles getting deeply hooked and killed [5]. Scientists have discovered that one key issue is the shape and size of the fishing hook and another is the type of bait the swordfish fleet uses. However, further study is needed to accurately characterize the impacts of various kinds of fishing technologies and practices [6].

In this study, we will focus on two parameters to characterize the two most important attributes of the fishery that relate to evaluating the potential for a permit auction system to reduce turtle bycatch: fishery profits and the turtle mortality ratio.

Fishery profit will be denoted by η throughout this paper and our code (“eta”). It denotes the proportion of revenue generated by the fishery which becomes profits. For example, if the revenue

is about \$1 million and $\eta = 0.17$, \$0.83 million is spent as expenses and only \$0.17 million becomes profit.

Turtle mortality ratio will be denoted by κ throughout this paper and our code (“kappa”). It is the proportion of turtle encounters that result in turtle mortality. For example, according to [7], in 2001, there were 76 turtle encounters and 46 of the turtles died; thus $\kappa \approx 0.61$.

8. Profits

Fishing firms of course focus on fishing as a source of revenue, but they also have some other ways to generate revenue, including investment, provision of goods and services to other fishermen, etc. For simplicity, we assume here that fishing firms can earn money in only two ways: fishing or investment.

We further assume for the purposes of this case study that they invest in a money market account with a fixed interest rate of 5%, without any uncertainty in returns. The interest rate earned on investment is an input into the model, and can be easily changed to investigate how fishermen might behave in different interest rate environments.

We have already modeled the revenue and expenses of one longliner. Now the profit of each fishing firm at year t is calculated as the sum of the profits from its money market account and from all the longliners it owns at year t :

$$\text{Profit}(t) = \text{Interest}(t) + \sum_{i=1}^{25} \text{Revenue}_i(t) - \text{Expense}_i(t)$$

The model provides sufficient flexibility for the fishing firms to decide how much money to invest in their money market accounts and how many swordfish targeted fishery trips they make in each period. We will also assume that the fishing firms make their decisions purely based on their profits and on the regulations the government enforces.

9. Simulations

9.1. Status quo

Currently, there are no turtle bycatch permits for the Hawaii swordfish longline fishery. There is an overall cap on the number of turtles that can be killed each year and once this is reached, the entire fishery is shut down. From our simulations, we see that the fishery will be shut down within 3 months in most years; our simulation’s granularity makes it difficult to ascertain exactly when this shutdown occurs. However, our projection comports with the fact that, in 2006, the fishery in Hawaii was shut down 6 weeks after it was reopened, suggesting that our model captures the main features of the current bycatch situation.

The current turtle bycatch policy is obviously problematic. That is, if a fishing firm (Firm A) adopts a very good way to reduce bycatch (new technology or a new fishing practice), it gains no financial advantage even if it kills no turtles because the cap will be reached by other firms and when that happens, Firm A needs to stop fishing as well. Indeed, Firm A will be worse off if the methods and gear it uses to avoid turtle bycatch increases its fishing costs.

This inference is borne out in our simulation. We assume that Firm A kills no turtles ($\kappa = 0$) while fishing but incurs extra expenses associated with avoiding turtles, lowering its profit margin by 5% relative to that of other firms that kill 61% of the turtles encountered and have a profit margin of 17%. Running 10,000 Monte Carlo simulations, we find

$$\overline{R_{A(\kappa,\eta)}} = 3.14, \quad \sigma < 0.01$$

where $R_{A(\kappa,\eta)}$ stands for the ranking of Firm A according to the wealth it has accumulated after 5 years and σ stands for the standard error of the result. This means on average Firm A is less profitable than average (average profitability results in a rank of 3).

On the other hand, if Firm A decides to try to generate more profit (profit margin 5% higher than others) at the cost of killing more turtles ($\kappa = 1$), it will indeed be better off according to our simulation.

After 10000 Monte Carlo simulations we find

$$\overline{R_{A(\kappa,\eta)}} = 2.84, \quad \sigma < 0.01$$

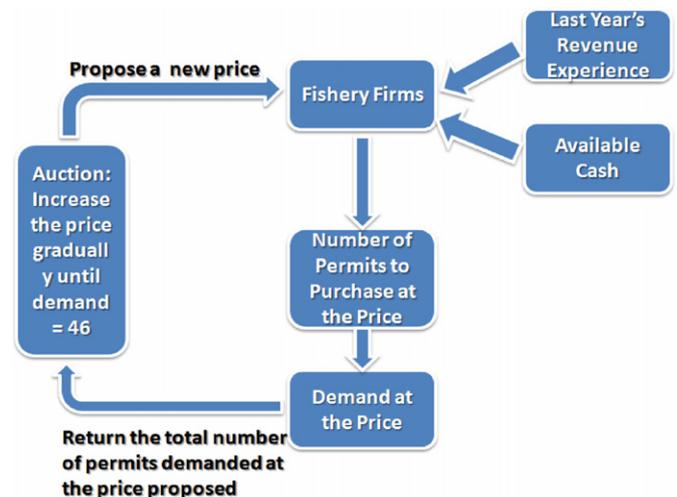
where $R_{A(\kappa,\eta)}$ and σ stands have the same meaning as before.

We conclude from the simulations that putting a cap on the number of turtles killed each year in the absence of measures that exact a financial cost associated with killing turtles or result in a financial benefit for avoiding turtles reduces a fishermen’s motivation to protect sea turtles. Thus, regulations (e.g., restrictions on the size and shape of the hulks and baits) and strong enforcement measures are extremely important in this case; they are essential for counter-acting the incentives created by the regulatory system.

9.2. Hypothetical auction of turtle bycatch permits

Integrating the existing cap (or an even lower cap) on sea turtle mortality with a permit auction and trading system has the potential to introduce incentives to avoid turtle bycatch. To investigate this potential, we assume that the cap on sea turtle mortality is set at the current level of 46.

In our simulation, the permit auction is conducted in the beginning of each year except that in the first year, permits are allocated free of charge. The turtle mortality that each fishing firm can incur before being shut down will be determined by the number of permits they own. For example, if Firm X purchased 2 permits from the auction in the beginning of the year and accidentally killed 2 turtles during its fishery trips in the first 2 months, then firm X’s longliners are no longer allowed to fish in the Hawaii-based fishery until next year.



The diagram above illustrates how an auction could be conducted. The auctioneer increases the price of a permit gradually from \$0. At each price, the auctioneer proposes the price to all fishing firms. Given the price, each firm will know how many permits it wants to buy. There is a trade-off between

spending money to buy permits and saving money in the money market account. The firm finds the number of permits (which must be between 0 and 46) that maximizes its expected profit over the next period. Then all firms return its numbers to the auctioneer who will add them up and see if it is below 46. If it is, then the price will be increased by a small amount. The process is repeated until the cap is reached.

10. Simulations and results in two scenarios

We investigated two scenarios within the context of a hypothetical auction of transferable turtle bycatch permits. We make use of estimates of turtle mortality ($\kappa = 0.61$) and fishery profits $v = 0.17$ based on Pradhan and Leung [1].

10.1. Scenario 1—reduced turtle bycatch at higher cost

In this scenario, we assume that fishermen have discovered a new way of prosecuting the longline fishery that can reduce κ (i.e., reduce the proportion of turtles killed after encounter) but at the same time decreases η (i.e., increases fishing costs). This is realistic if it is assumed that any method that results in lower turtle mortality at no cost would already have been developed and deployed in order to increase fishing opportunities under the total turtle mortality cap. This scenario does not depend on the introduction of a revolutionary new technology. The innovation could be simply a different kind of hook (e.g., the “J” hook that appears in tests to reduce turtle mortality), the use of different areas for fishing that result in lower turtle encounter rates, the use of different techniques to release hooked turtles, or some combination of methods. Since for the purposes of this simulation fishing practice and technology is completely characterized by its κ and η , the way that turtle mortality is reduced is immaterial.

To investigate whether this type of innovation would likely be implemented, we simulated the following scenario: Firm A starts fishing in the new way (“low bycatch fishing”) while others prosecute the fishery in the conventional way. The turtle bycatch permits are distributed equally among all firms at the beginning and an auction is conducted afterwards. This sequence is intended to increase the acceptability of the permit auction to the industry. Since permits the first year are essentially free, fishing firms can gauge the economic value of the permits without over-committing themselves during the bidding process.

In our model, fishing firms can only generate revenues by fishing or by investing in a money market account. This scenario was simulated for 5 years and the firms were ranked by the amount of money they have at the end of the 5 years. Mathematically we translate the conditions of this scenario to

$$\overline{R_{A(\kappa,\eta)}} + \sigma < 2$$

where $\overline{R_{A(\kappa,\eta)}}$ is the average of the rankings obtained from Monte Carlo simulation for Firm A, and σ is the standard error of the simulation.

For each κ (turtle mortality ratio) there will be a minimal η (profit) required such that the firm who uses the new method will be able to successfully compete with other firms (Fig. 2). Any fishing firm for which the pair (κ,η) lands above the curve in the graph will likely be able to successfully compete.

For example, when $\kappa = 0.4$, $\eta_{\min} = 0.148$. This suggests that if a firm can find a way to reduce turtle mortality by about a third without reducing profits by more than 13%, then fishermen are likely to use this new method. The simulation also suggests that the total amount of money that would be spent on permits may be as low as 2.7% of the industry’s total revenue.

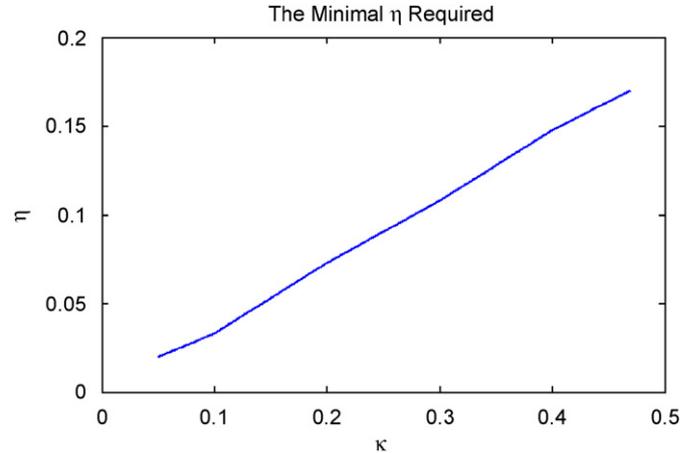


Fig. 2. Minimal profitability required for successful competition by fishing firm using turtle bycatch reduction methods.

Table 2

Relationship between turtle mortality ratio and profitability

κ	η_{\min} (%)
0.7	19.8
0.8	22.4
0.9	24.9
1.0	27.7

10.2. Scenario 2—will the added costs of permits induce higher fishing effort?

It is possible that setting up an auction for turtle bycatch permits could induce higher levels of fishing effort, as some fishermen may seek to recoup permit costs by catching more fish. To investigate this possibility, we set the turtle mortality ratio $\kappa > 0.61$ and constrained $\overline{R_{A(\kappa,\eta)}} + \sigma < 3$, meaning we set a very high turtle mortality ratio but also force the firm’s ranking to be very high by revenue (ranking < 3 , i.e., they placed first or second). We then ran simulations to find the η_{\min} such that η_{\min} is the least profit Firm A needs to be more profitable than average even if it kills a relatively large number of turtles. This scenario is constructed to determine how much extra money the firm needs to make if it fishes extremely inefficiently but still wants to generate more revenue than its peers. For levels of k between 0.7 and 1.0, η_{\min} ranges from 19.8% to 27.7% (Table 2).

These results suggest that Firm A would need to improve its profits significantly to be better off if it kills turtles. For example, if it kills 70% of the rare turtles it caught ($k = 0.7$), then it needs to improve its profit by at least 16.5%. If it kills all of them, then it has to improve its profit by at least 63%. Clearly, increasing profits by 63% is an unrealistic barrier to overcome in order to compensate for fishing in a very inefficient way.

We conclude from this hypothetical scenario that the negative impact of the permit auction is quite limited, meaning the firm needs to increase profits beyond a reasonable amount if it were to fish in such a way that kills turtles but still wanted to make more money than its peers. Negative impacts could include, for example, a firm fishing without regard to turtle bycatch, increasing revenues so much that permit prices increase to the point that other firms cannot afford them, allowing the firm to dominate the fishery. Our analysis suggests that the profits required to result in this scenario are unrealistically high. However, given the fact some species of the sea turtles are

extremely rare, existing regulations will still be necessary even under an auction permit system.

11. Conclusions and suggestions

The simple model of the Hawaii swordfish longline fishery we present here suggests that an auction of sea turtle bycatch permits integrated with a cap and trade system could potentially create incentives for bycatch reduction. Regulations such as gear restrictions, area restrictions and a cap on total turtle mortality have successfully helped to stop the problem from getting worse [8]. But regulations, like other traditional methods, fail to give fishermen economic incentives to protect sea turtles and hence usually require strong enforcement to be effective.

Given the current turtle bycatch regulations, fishermen who try to protect turtles cannot gain financially, since turtles that individuals conserve (often at some additional cost) can be caught by others. In contrast, auctioning bycatch permits allows fishermen to incorporate the costs of turtle bycatch into their businesses. Allowing them to transfer permits could introduce an incentive to reduce turtle bycatch, in order to reduce permit costs. If permits were issued at no cost for the first year, the fishing industry could determine how best to incorporate the future costs of the permits into their businesses, planning their capital expenditures and preparing appropriate bids when the auction is initiated.

Our model results also suggest that the auction system may not induce higher fishing effort as a way to recoup permit costs. However, due to uncertainties, some combination of the auction system and existing regulations would likely be necessary to ensure that the auction system does not result in higher fishing effort, greater turtle mortality or other adverse impacts.

We also projected potential permit prices and found that for the cases we studied, permit costs averaged about 2–3% of the fishery's total revenue, suggesting that an auction would not likely impose prohibitive costs. Revenues generated through the auction could be used in a variety of ways, depending on specific fishery management objectives. For example, auction revenues could be used for reducing other threats to sea turtles. Using the revenues to reduce other fees that fishing firms pay proportionally to fishermen's profits would not likely alter the incentives for sea turtle conservation that could potentially be created with an auction-cap-and-trade system.

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