Limited Access and Vessel Heterogeneity in Atlantic Pelagic Fisheries: Evaluating Draft Amendment 1 of the North Atlantic Swordfish FMP

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Abstract

Overcapitalization in the U.S. Atlantic Swordfish fishery has led to a proposed limited access system. A bioeconomic programming model was developed to evaluate the proposed program under various assumptions regarding fleet heterogeneity and composition. Results indicate that regulations based on more realistic assumptions will lead to higher industry profits.

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The commercial Atlantic swordfish (*Xiphias gladius*) fishery in the U.S. landed approximately five million pounds of swordfish with an ex-vessel value of over $16 million in 1996 (National Marine Fisheries Service, NMFS, 1997b). The fishery is primarily composed of pelagic longline vessels distributed along the East Coast of the U.S. and the Gulf of Mexico. Collectively, this fleet harvested approximately 98 percent of the north Atlantic swordfish landed in the U.S. (NMFS, 1997c). Historically, the fleet has also accounted for a significant portion of total U.S. commercial big eye and yellowfin tuna landings (NMFS, 1997a).

According to NMFS, there are an excessive number of permitted vessels relative to the annual U.S. quota. In 1996, 1,531 commercial fishing vessels were permitted to land north Atlantic swordfish in the U.S., but only 334 recorded annual landings of at least one swordfish since 1987 (NMFS, 1997c, p. 17). And, only 231 of those vessels landed more than 18 swordfish annually (the average number of fish needed to gross $5,000). The potential effort that exists from the approximately 1,200 inactive vessels could undermine management goals aimed at creating a balance between fleet size and the annual quota (Federal Register, 1997a). Consequently, a limited access program has been proposed under Draft Amendment 1 to the Fishery Management Plan for Atlantic Swordfish (NMFS, 1997c). Such a program could increase returns to active participants by eliminating speculative permit holders and preventing an increase in the number of permits (above 1,531). It could also provide the first step toward joint regulation of all vessels fishing with pelagic longline gear (NMFS, 1997c).

In 1996, 259 pelagic longline vessels participated in the swordfish fishery (NMFS logbook data; Larkin, Lee, and Adams). The average pelagic longline vessel was built in 1980, was 57 feet in length, and displaced 68 gross tons. These types of vessels place "sets" consisting of, on average, 632 baited hooks across 25 miles of line. In 1996, each pelagic longline vessel averaged 5.1 sets per trip and 22.6 swordfish per trip (landed) during 12.2 trips. Landings for the average trip in 1996 were composed as follows: 30 percent swordfish, 33 percent BAYS tunas (big eye, albacore, yellowfin, and skipjack), 15 percent dolphin fish (mahi-mahi), 15 percent coastal sharks (hammerhead, silky, dusky, etc.), and 7 percent other fish (wahoo, king mackerel, oilfish, etc.). The total variable cost per trip averaged $7,331 and included fuel, ice, bait, light sticks, groceries, and docking and unloading fees (Larkin, Lee, and Adams).

Larkin, Lee, and Adams (1998) showed that the Atlantic pelagic longline fleet is characterized by wide distributions of vessel sizes, catch rates, catch composition, trip lengths, number of sets per trip, and variable costs. Of the 259 vessels that landed swordfish in 1996, 38 percent were small vessels (30 to 49 feet in length), 39 percent were medium (50 to 69 feet) and 23 percent were large (70 to 96 feet). Collectively the fleet completed 3,171 trips. Each trip averaged 5.1 sets, but the actual number of sets ranged from 1 to 26. The majority of trips (51 percent) consisted of 1 to 4 sets, 26 percent placed from 5 to 7, 14 percent placed from 8 to 10, and only 9 percent placed more than 10 sets per trip. The number of swordfish landed per trip ranged from 6 to 161 depending on vessel length and the number of sets placed. The catch composition also varied, the highest swordfish landings (in number of fish and percentage of catch) were recorded during trips placing more than 10 sets. Average trip costs ranged from $1,653 for small vessels placing from 1 to 4 sets to $15,083 for medium vessels placing 11 to 26 sets.

To compare the limited access alternatives proposed in Amendment 1, an age-structured bioeconomic programming model was developed. The model integrated the biological dynamics of the north Atlantic swordfish stock with observed characteristics of the relevant fisheries (swordfish, dolphin fish, BAYS tunas, coastal sharks, and other) and the U.S. pelagic longline fleet. This model is used to evaluate the economic effects of domestic regulations that would reduce domestic (U.S.) fleet size.

Four scenarios are examined:

(1) Scenario 1: Base Model, Status Quo

Purpose: Provides an estimate of the value of the fishery under current regulatory assumptions that regard the fleet and fishing behavior as homogenous.

(2) Scenario 2: Base Model, NMFS' Preferred Alternative (Alternative 12)

Purpose: Provides an estimate of the change in the value of the fishery under the proposal to reduce the number of permits (i.e., vessels) to 231.

(3) Scenario 3: Base Model, Net Revenue Maximizing Solution

Purpose: Provides an estimate of the change in the value of the fishery when the model is allowed to choose the fleet size that maximizes the value of the fishery.

(4) Scenario 4: Heterogeneous Fleet Model, Net Revenue Maximizing Solution

Purpose: Provides an estimate of the change in the value of the fishery when heterogeneity in the fleet is considered and the model is allowed to choose the fleet size, composition, and number of sets per trip that maximizes the value of the fishery.

The base model simulations (Scenarios 1 through 3) assume a fleet comprised of 'typical' pelagic longline vessels that take the average number of trips observed in 1996, at the average cost, and land the average number of each species per trip. The heterogeneous fleet model (Scenario 4) tracks the number of vessels by size and the type of trip by number of sets placed. Costs and catch composition are also assumed to vary based on observed behavior in 1996.

Data Sources

The biological parameters are based on the 1996 stock assessment and were obtained from various reports by the Standing Committee on Research and Statistics (SCRS), the research division of the International Commission for the Conservation of Atlantic Tunas (ICCAT; tables 12, 15, 16, 18 and p. 44 and 47). ICCAT is the regulatory body that oversees the harvest of swordfish (and other tuna-like species) by all nations. The SCRS figures represent the most recent, comprehensive information on the stock. The next assessment will occur in 1999 before the next management period (beginning in 2000).

Economic parameters concerning fishing effort include the average catch rate, fleet size, and number of trips per vessel per year and were generated from summary reports required by NMFS. This information was augmented with the U.S. Coast Guard vessel database, which provides specific vessel characteristics (e.g., length). Average weights for the majority of species were obtained from dealer receipts and observer reports (NMFS-SEFSC, personal communication). Average prices were based on reported landings and total value of the landings for the longline fleet in the Atlantic and Gulf of Mexico (NMFS, Fisheries Statistics and Economics Division, personal communication). Average swordfish price at age was constructed from average premiums observed in the southeast in 1996 (J. Bennett, NMFS_SEFSC, personal communication). The older (i.e., heavier) cohorts received price premiums of, approximately $0.25 to $0.50 per pound. These economic parameters are fully described in the report by Larkin, Lee, and Adams (1998).

Model Specification

The following equations describe the dynamics of the north Atlantic swordfish fishery. Variables and parameters are identified through the use of capital and lower case letters, respectively. Table 1 contains a glossary of symbols.

Swordfish Recruitment:

(1) $$X_{y,a=1} = rec_y$$

Population of the older swordfish cohorts (numbers at age) in the first year:

(2) $$X_{y=1,a+1} = num_{a+1}$$

Interyear swordfish population dynamics:

(3) $$X_{y+1,a+1} = X_{y,a} \cdot e^{-Z_{y,a}}$$

Total instantaneous swordfish mortality rate:

(4) $$Z_{y,a} = m + F_{y,a}$$

Constraint on annual total swordfish fishing mortality:

$$(5) \qquad F_{y,a} \leq f_a^o$$

Annual swordfish harvest-at-age (numbers killed by fishing):

$$(6) \qquad H_{y,a} = \left(\frac{F_{y,a}}{Z_{y,a}}\right) \cdot X_{y,a} \cdot \left(1 - e^{-Z_{y,a}}\right)$$

Allocation of annual harvest quota by nation:[1]

$$(7) \qquad \sum_g SH_{y,g} = 1$$

Annual harvest quantity (*HQ*) of swordfish by the U.S. in live weight:

$$(8) \qquad HQ_{y,a,g} = H_{y,a} \cdot w_a \cdot SH_{y,g}$$

Annual U.S. landings (of legal-sized swordfish) in dressed weight:[2]

$$(9) \qquad TAC_y = \sum_{a=3}^{5+} HQ_{y,a,g=US} \cdot \alpha$$

Net present value of returns (*NPVR*) to U.S. commercial longliners:

$$(10) \qquad NPVR = \sum_{y=1}^{5} \left(\frac{1}{1+r}\right)^y \cdot \left(\sum_i TR_{y,i} - TC_y\right)$$

Total annual swordfish revenue:[3]

$$(11) \qquad TR_{y,i=swo} = \sum_{a=3}^{5} p_a^{swo} \cdot HQ_{y,a,g=US} \cdot \alpha$$

Total annual revenue from the sale of the non-swordfish species:

$$(12) \qquad TR_{y,i\neq swo} = \sum_{i \neq swo} (p_i \cdot wght_i) \cdot \sum_j \sum_k FPT_{i,j,k} \cdot tpv_j \cdot SPT\_SH_{y,j,k} \cdot V_y \cdot V\_SH_{y,j}$$

Number of other fish landed per trip:

$$(13) \qquad FPT_{i\neq swo,j,k} = FPT_{i=swo,j,k} \cdot prop_{i\neq swo,j,k}$$

Balance equation for landings of legal-sized swordfish in each year:

$$(14) \qquad \sum_{a=3}^{5+} (H_{y,a} \cdot SH_{y,g=US}) \equiv \sum_j (\sum_k FPT_{i=swo,j,k} \cdot SPT\_SH_{y,j,k} \cdot tpv_j) \cdot V_y \cdot V\_SH_{y,j}$$

Total annual variable cost:[4]

(15) $$TVC_y = \sum_j \sum_k vcpt_{j,k} \cdot tpv_j \cdot SPT\_SH_{y,j,k} \cdot V_y \cdot V\_SH_{y,j}$$

Fleet composition in each year:

(16) $$\sum_j V\_SH_{y,j} = 1 \qquad \forall y$$

Share of trips by number of sets for each vessel size class in each year:

(17) $$\sum_k SPT\_SH_{y,j,k} = 1 \qquad \forall y, j \qquad .$$

Model Execution and Validation

The model maximizes the net present value of returns to the commerical harvest by pelagic longline vessels in the U.S (i.e., *NPVR* of equation (10)). The returns represent the sum of monies to be divided among the vessel owner (to cover fixed costs), captain, and crew and, therefore, represent a measure of producer surplus. For the north Atlantic swordfish fishery, consumer surplus is assumed negligible since domestic production accounts for less than a quarter (22 percent) of domestic supply (Federal Register, 1997). To maximize *NPVR*, the equations are simultaneously solved using the nonlinear solver in the General Algebraic Modeling System (GAMS; Brooke, Kendrick, and Meeraus).

The primary calibration and validation criterion is the ability of the model to predict the average annual U.S. quota. The model produced an annual average domestic *TAC* of 2,356 metric tons (mt) dressed weight (dw). This figure is compared to the average quotas set by ICCAT for the 1997 through 1999 fishing years. Only these years are used for comparison since the model was based on the 1996 stock assessment and regulations in effect beginning with the 1996 season (e.g., minimum size).

The average 1997-99 U.S. quota was 2,393 mt dw. The approximate 2 percent *TAC* difference is, therefore, attributed to rounding error and the change in regulations governing landings of juveniles that occurred during the modeling period. The magnitude of this discrepancy is considered negligible. Moreover, the 2 percent underestimate of *TAC* is offset by the failure of the model to reserve 2 percent of the quota for the harpoon sector.

Results

Scenario 1: Base Model, Status Quo

Total discounted net returns for the domestic commercial longline fishery were $30.4 million from the annual 2,356 mt *TAC*. Swordfish landings accounted for approximately 51 percent of the returns despite accounting for just 30 percent of the total number of fish landed. Each trip landed approximately 18 swordfish per trip (i.e., $FPT^*_{f=swo}$=18.1, on average).

To examine the effect on the stock over the 5-year management horizon, the number of fish in the final period was compared to the initial stock size (i.e., *rec* plus *num*). The status quo scenario resulted in a year-5 stock size of 1.66 million fish. This represents an increase of 4 percent over the initial number of swordfish. Given that the number of older cohorts increased, the effect on biomass would be larger. The implication is that the upper bounds on fishing mortality at age established by ICCAT following the last stock assessment are effective at rebuilding the stock (assuming compliance by other nations).

Scenario 2: Base Model, NMFS' Preferred Alternative (Alternative 12)

To simulate NMFS' preferred alternative under the proposed limited access program, the number of vessels (i.e., representing the number of non-transferable permits) was capped at 231 (NMFS, 1997c, p. 19). By reducing the number of vessels but assuming that each operates as before (i.e., *tpv* constant), the number of swordfish landed per trip is allowed to vary. Allowing the catch rate to adjust to the fleet size in equation (14) preserves the maximum U.S. quota share of 29 percent.

An 11 percent reduction in fleet size (while maintaining the number of trips per vessel) following the implementation of NMFS' preferred alternative would increase discounted net returns ($NPVR^*$) 28 percent ($9 million). In addition, average swordfish landings increased in order to maximize the U.S. quota share. Specifically, the number of swordfish landed per trip increased from 18.1 to 20.2. Consequently, this domestic policy would increase the average annual return per vessel.

Scenario 3: Base Model, Net Revenue Maximizing Solution

In this scenario, fleet size in each year is allowed to vary while fishing behavior is held constant. Using the observed swordfish catch rate ($FPT_{i=swo}$=22.6) and average number of trips per vessel (*tpv*=12.2), returns to the industry over the 5-year management period would be maximized with an average fleet size of 207 vessels. Collectively, the vessels would generate $45.6 million, which represents an increase of 53 percent over the status quo. This fleet, however, would contain 20 percent fewer vessels than observed in 1996 and 10 fewer vessels lower than NMFS' preferred alternative.

Scenario 4: Heterogeneous Fleet Model, Net Revenue Maximizing Solution

When the model is allowed to determine the number of vessels that would maximize the net present value of returns, the fleet generated $74.1 million. On average, 177 vessels would operate annually. In the first year, the model predicted the 157 vessels all should be 'small' (i.e., 30 to 49 feet) and place from 5 to 7 sets per trip. In the remaining four years, the model predicted that approximately 182 vessels would be needed and all vessels should be of medium length (i.e., 50 to 69 feet) and should set from 8 to 10 sets per trip. The number and composition is different in the first year due to the composition and size of the population in the first year (i.e., num_{a+1}) and the relative catch and average cost per trip for each size class. The marginal values indicate that these two types of operations generate similar returns but the medium length vessels setting from 8 to 10 sets are more efficient in the final years as the stock size and age-structure changes.

Since the U.S. will harvest its 29 percent share in each year (regardless of the distribution among vessel and trip types), the annual average *TAC* and ending biomass did not change. However, the proportion of discounted returns from swordfish fell from 51 percent to 41 percent. This is because the medium length vessels that place from 8 to

10 sets per trip, land relatively more of the higher-valued other species (i.e., BAYS tunas and dolphin fish) than the average vessel.

Discussion

According to NMFS, the Atlantic pelagic swordfish fishery is overcapitalized. Approximately 1,200 permitted vessels have been 'inactive' since 1988. Given the observed heterogeneity in vessel size, trip characteristics, costs and returns reported by Larkin, Lee, and Adams (1998), the current fleet composition and pattern of fishing behavior (number of sets per trip), does not maximize returns.

If permits were allocated according to the preferred alternative, 28 vessels that were active in 1996 would be eliminated from the fishery (a decline of 11 percent). If rights to quota were allocated to these permit holders and were transferable, the quota shares would likely be traded to the most efficient firms (assuming a workable trading market) and approximately 20 percent of the fleet would exit the fishery. According to the model, net returns to vessel owners (to cover fixed costs), captains, and crew would increase 38 percent. In addition, the fleet composition would change and consist of shorter vessels taking longer trips (i.e., placing more sets per trip).

Although the model results cannot be used to make predictions about what will happen under various scenarios (due to the use of debatable assumptions and changing parameter values), acknowledging fleet and trip heterogeneity can improve model specification and resulting estimates of relative effects from alternative policies.

Endnotes

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[1] Allocation of annual harvest is divided among the ICCAT member nations, primarily Canada, Spain, Portugal, and the United States. For simplicity, the harvest is assumed allocated between two groups, the United States and 'other'. The U.S. received 24 percent of the total Atlantic quota in 1996 and will receive 29 percent annually through 1999 (Federal Register 1997c). Since the U.S. share of future quotas is unknown at this time, the U.S. share is not allowed to exceed its present level.

[2] The conversion is necessary since the *TAC* is specified in dressed weight. On average, cohorts age 3 and up weigh more than the minimum landing size of 33 pounds dressed weight (ICCAT, table 15; Federal Register 1997c). Note that TAC represents the maximum landings in weight, not catch.

[3] Price by live weight is used with dressed weight since conversion factors for the other species were unavailable, therefore, revenues will be underestimated by the average dressed to round weight conversion.

[4] Fixed vessel costs have not been collected for this fleet and are difficult to estimate since: (1) vessels are constructed out of a variety of materials which affects its value and life, (2) vessels vary in age by decades, and (3) the use of expensive navigational equipment may not be standard nor correlated with vessel-age or firm-size (Squires, Alauddin, and Kirkley). Given the short-run scope of the analysis, omission of fixed costs is not expected to bias the results.

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Table 1. Glossary of Symbols

Indices:	
y	$y = 1, 2, \ldots 5$ time in years
a	$a = 1, 2, \ldots 5+$ swordfish age in years (5+ is accumulator age)
g	$g = other, US$ nations sharing total swordfish quota
i	$i = dol, BAYS, coast, other$ non-swordfish species landed
j	$j = sm, med, lg$ vessel length categories
k	$k = s1\_4, s5\_7, s8\_10, s\_11$ number of sets per trip categories
Exogenous Variables and Constants:	
rec_y	Annual recruitment of age 1 swordfish
num_{a+1}	Initial stock size of older cohorts (numbers of swordfish at age 2,…5+)
m	Natural (instantaneous) mortality rate
f_a^o	Maximum fishing mortality at age
w_a, $wght_i$	Weight at age of swordfish (live), weight of non-swordfish (dressed)
α	Conversion factor from live to dressed weight for swordfish
r	Annual discount rate
p^{swo}_a, p_i	Price at age for swordfish, average price for non-swordfish species
tpv_j	Trips per vessel per year by vessel size class
$prop_{i,j,k}$	Proportion of non-swordfish landed relative to swordfish by vessel length and trip type (i.e., number of sets placed)
$vcpt_{j,k}$	Variable cost (supplies and misc.) per trip by vessel length and trip type
Endogeneous Variables:	
$X_{y,a}$	Number of swordfish at age in each year
$Z_{y,a}$, $F_{y,a}$	Total and fishing swordfish mortality in each year at age, respectively
$H_{y,a}$	Number of swordfish at age harvested (and killed) in each year
$SH_{y,g}$	Share of the annual swordfish for each nation group ($\Sigma_g SH_{y,g} = 1$ where $SH_{y,g=US} <= 0.29$)
$HQ_{y,a,g}$	Total weight of swordfish at age harvested annually by each nation
TAC_y	Total allowable catch (dressed weight of legal swordfish) in each year
$NPVR$	Net present value of total returns (revenues less variable costs) in U.S.
$TR_{y,i}$	Total annual revenue by species
TVC_y	Total annual variable costs
V_y	Fleet size in each year
$V\_SH_{y,j}$	Share of fleet by vessel size in each year ($\Sigma_j V\_SH_{y,j} = 1$)
$SPT\_SH_{y,j,k}$	Share of trips by number of sets in each year by size ($\Sigma_k SPT\_SH_{y,j,k} = 1$)
$FPT_{i,j,k}$	Number of fish landed by the number of sets placed and vessel size