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Integrating Porpoise and Cod Management: A Comparison of Days-at-sea, ITQs, and Closures

KATHRYN D. BISACK
National Marine Fisheries Service

Abstract *The purpose of this study is to determine if management measures based on effort reductions, in particular days-at-sea (DAS) controls, can approach a harbor porpoise individual transferable quotas (ITQ) program in terms of efficiency. The intent is to expand discussions of combining fishery-porpoise management actions. The New England sink gillnet fishery is examined by using a numerical bio-economic model. Year-round and seasonal surcharges in combinations with overall DAS reductions are investigated. Results indicate that several programs for marine mammal protection can achieve the same conservation outcome with modest differences in industry profits. At the industry level, the program selection decision may then rest on the goal of cod management, since reductions in cod landings are much greater under the DAS year-round (59–63%) versus seasonal (39–46%) programs. Significant differences in vessel profits, however, may make consensus on the appropriate program difficult.*

Key words Fisheries management, individual transferable quotas, protected species, marine mammals, turtles, bycatch.

JEL Classification Codes Q220, Q280, Q570, Q580.

Introduction

Commercial fisheries incidentally capture and kill marine mammals and sea turtles around the world. Given the potentially competing objectives of fisheries and protected species management, there remains a need to develop and analyze a range of management tools that address these objectives in an integrated manner. In fisheries economics it has been shown that output management with individual rights, in particular individual transferable quotas (ITQs), are superior compared to other management measures in terms of profitability and sustainability of fisheries (*e.g.*, Boyce 1992; OECD 1997; Morey 1986; National Research Council 1999; Geen and Nayer 1988). However, there are few studies that empirically evaluate management measures for protected species and fish simultaneously (Bisack and Sutinen 2006; Pradhan and Leung 2006; Curtis and Hicks 2000; Hoagland and Jin 1997). This paper systematically evaluates the use of input and output controls to simultaneously manage fish and protected species.

In the United States of America (USA), the National Marine Fisheries Service (NMFS) is subject to several laws designed to sustain fisheries and protected species

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Kathryn Bisack is an economist in the Protected Species Branch of the Northeast Fisheries Science Center (NEFSC), 166 Water Street, Woods Hole, MA 02543, email:Kathryn.Bisack@noaa.gov
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stocks. The Marine Mammal Protection Act (MMPA 1972) and the Endangered Species Act (ESA 1973) require the protection of marine mammals and sea turtles from commercial fishing with limited economic guidance. The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA 1976) and the Sustainable Fisheries Act (SFA 1996) require a national program to insure conservation of fish stocks and to realize the full potential of the nation's fishery resources. An amendment to the SFA defined a fishing community and included a mandate (National Standard 8) to "take into account the importance of fishery resources to fishing communities." In addition, NMFS must address the National Environmental Policy Act (NEPA 1969), Executive Order 12866 (1993)[1] and the Regulatory Flexibility Act (RFA 1980), which requires the analysis of economic impacts of proposed regulatory actions from national to vessel-level impacts as well as for distributional impacts. Consequently, the NMFS is responsible for regulating different resources (fish and protected species) used or accessed by the same communities under different acts with different goals and guidelines. There clearly is a need for integrated analysis and management.

To achieve the objectives, NMFS has implemented a number of input and output controls in fisheries. The principle means used to protect marine mammals under the MMPA have been input restrictions in the form of gear modifications and closures.[2] Under the MSFCMA and SFA, both input and output tools have been used. Input restrictions to reduce effort have included limiting DAS, requiring days out of the fishery, and closures. Output restrictions have included trip limits and landings quotas. The relationship between fisheries management actions and reduced protected species bycatch has been acknowledged and accounted for in protected species management; however, full integration remains elusive.

The purpose of this study is to determine if management measures to reduce protected species bycatch based on effort reduction, in particular DAS, can approach a harbor porpoise ITQ policy in terms of efficiency while concurrently achieving fisheries goals. If an effort-based action is appropriately designed to account for spatial and temporal aspects of the fishery and bycatch, the industry-level economic impacts should be similar; however, there may be distributional differences between management measures. As a case study, I use the New England multispecies sink gillnet fishery in 1994–95, which has a bycatch of harbor porpoise.[3] At that time, management for both the fishery and marine mammal bycatch were limited, and harbor porpoise bycatch was at a high level. The actions initiated in 1996 successfully reduced bycatch by 90% in 1998; however, bycatch has increased since then and is once again a concern in 2007. Management efforts to rebuild multi-species stocks intensified after 1994, and there were regular changes in regulations. Yet, several multispecies stocks currently remain overfished, so restrictive management actions, including DAS limits, are likely to continue for some time. The model and results illustrate that the multiple objectives of NMFS can be achieved simultaneously with several alternative management programs.

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[1] See www.whitehouse.gov/omb/inforeg

[2] Gear modifications and closures have also been implemented under the ESA to reduce the lethal take of sea turtles in the Chesapeake Bay pound net (NOAA 2006b), Atlantic sea scallop dredge (NOAA 2006c), and the summer flounder trawl fishery (67 *Federal Register* 18833, April 17, 2002).

[3] The use of data from an earlier period allows for a systematic comparison of management measures that have the potential to deal jointly with objectives for fish stock rebuilding and porpoise bycatch avoidance in a commercial fishery, without the noise created by ongoing changes in management.

Background

Gillnet Fishery

Sink gillnet vessels operate from Maine to North Carolina. This study focuses on the vessels that fish in the Gulf of Maine north of 42º N. Vessels leave port in the early hours of the morning, haul their catch, reset their gear, and return to port the same day. A vessel typically hauls four to eight strings of gear per trip, where one string is around 3,000 feet in length. The gear is set in the water to soak for 24 to 72 hours, after which it is hauled and reset. Harbor porpoise (*Phocoena phocoena*) become entangled in the gear and suffocate. Target species landed by this fleet include cod (*Gadus morhua*), spiny dogfish (*Squalus acanthias*), pollock (*Pollachius virens*), monkfish (*Lophius americanus*), and flounder (*Pleuronectiform*). Species landings vary by mix, season, and area. For example, in a season area where groundfish landings, such as cod, are prevalent, dogfish landings are typically absent. The spatial temporal bio-economic model presented captures the mix and variation of species catch rates.

In 1995, the Gulf of Maine sink gillnet fleet consisted of 200 vessels landing 15,140 tons of fish and generated revenues of $16.1 million (Bisack and Sutinen 2006). The five major target species were cod, which accounted for 19% of landed weight and 36% of revenues; spiny dogfish (60% weight, 20% revenues); pollock (10% weight, 20% revenues); monkfish (6% weight, 12% revenues); and flounder (5% weight, 12% revenues). The observer program placed at-sea technicians on more than 50% of these vessels and observed 5.6% (864.5 tons) of total landings. The observer program also records trip costs including fuel, oil, food, bait, and water. Trip operating costs recorded by the observer program showed the average operating cost to be $56.86 (CV=0.96) per trip.

Harbor Porpoise Management

Under the MMPA, if the level of incidental takes of marine mammals is above the potential biological removal (PBR) rate, the bycatch must be reduced.[4] Take reduction teams (TRTs) are formed and tasked with the development of management plans that reduce the serious injury and mortality of stocks to levels below PBR. In the northeastern USA, plans have been developed for harbor porpoise, northern right whales, and coastal bottlenose dolphins (Resolve 1996; NMFS 2005; NOAA 2006a).[5] Regulations have included gear modifications and closures.

The Gulf of Maine/Bay of Fundy (GOM/BOF) harbor porpoise stock in the USA ranges from North Carolina to Maine. The best estimate of the population size based on 1991, 1992, and 1995 abundance survey data was 54,300 animals, with an allowed PBR of 483 (Waring, Quintal, and Swartz 2000).[6] The average annual bycatch

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[4] Potential biological removal (PBR) is defined by Wade and Angliss (1997) as "the maximum number of animals, not including natural mortalities, which may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population." PBR is the product of three elements: the minimum population estimate, half the maximum net productivity rate, and a recovery factor.

[5] Right whale deaths have been associated with pot gear (including lobster) and the sink gillnet, while bottlenose dolphin and harbor porpoise takes have occurred primarily in sink gillnet fisheries.

[6] In 1998, PBR for harbor porpoise was increased to 747 animals and decreased to 610 animals in 2007. This is a result of new sightings survey data and therefore new population estimates (Waring *et al.* 2006, 2007). However, population and PBR estimates used in this study were based on the data that were available in 1995, when the TRP was being developed and for the period applicable to the data used.

estimate for 1991-1995 was 1,833 animals (Waring, Quintal and Swartz 2000).[7] The Harbor Porpoise Take Reduction Team (HPTRT) convened in 1996, and the Take Reduction Plan (TRP) was implemented in January 1999 (NMFS 1998).

Prior to implementation of the Plan, Amendment 5 of the Northeast Multispecies Fishery Management Plan (FMP) implemented closed areas and required pingers to control harbor porpoise bycatch in the U.S. Northwest Atlantic.[8] Pingers are acoustical devices attached to gillnets to deter porpoise. Starting in 1996, closures increased in size and duration to try to reduce porpoise bycatch to below PBR. These expansions reflected the inter-annual variability in harbor porpoise migration patterns, influenced by exogenous factors such as water temperature and prey availability.

The TRP specifically recognized the reduction in harbor porpoise bycatch from rolling closures implemented under Amendment 5 of the FMP. However, these rolling closures were insufficient to reduce the porpoise takes to below PBR (NMFS 1998; 63 Federal Register 66464, December 2, 1998). Therefore, the HPTRT Plan included additional closures and mandatory pinger use to further reduce harbor porpoise bycatch.

By 1998 bycatch in the Northeast sink gillnet fleet was reduced by 90% to levels below PBR (Waring, Quintal, and Swartz 2000). Until recently, the combination of Plan requirements and effort reduction under the FMP kept harbor porpoise takes below PBR. However, porpoise bycatch estimates started to increase in 2002 and have exceeded PBR levels since 2004 (Waring *et al*. 2006). In December 2007, the HPTRT reconvened to discuss potential modifications to current regulations.

Northeast Multispecies Fishery Management Plan

The New England Fishery Management Council (NEFMC) implemented the FMP to reduce the mortality on twelve FMP species, divided into 19 stocks. In 1994 a DAS program was initiated which limits the number of days that a vessel can fish; each permit holder received a specific number of DAS. In 1995, the NE sink gillnet fishery landed 96% of the proposed 1996 Gulf of Maine (GOM) cod total allowable catch (NMFS 1996). These landings would have been acceptable if no other gear types were harvesting GOM cod; however, the gillnet fleet accounted for only 45% of GOM cod landings (Mayo and Col 2006). In 1996, Amendment 7 of the FMP implemented an accelerated DAS reduction program for the sink gillnet and trawl fisheries to reduce fishing effort by 50% in 1997 from 1994 levels (NEFMC 1996).

Since 1994 there have been numerous management changes to the FMP, which have affected the New England sink gillnet fleet. By 2004, in an effort to allow stock rebuilding, the annual allocation of DAS dropped by 82%, while trip limits were tightened (NEFMC 2006). Despite these actions, in 2006 several stocks, including GOM cod, remained below their rebuilding targets.

To address the need for significant reductions in fishing effort on several stocks, an emergency rule published on April 13, 2006 (NMFS 2006a) implemented differ-

[7] During the same period, the Gulf of Maine harbor porpoise bycatch was 1,521 animals. The Gulf of Maine, a geographic subset of the Northeast, is the focus of this study.
[8] The New England Fishery Management Council (NEFMC) proposed a four-year program to reduce the harbor porpoise bycatch off New England to 2% of the estimated harbor porpoise population size per year. To achieve this goal, the NEFMC recommended phasing in time and area closures to sink gillnet gear, such that take levels would be reduced by 20% each year over the four-year period. The first closure was implemented in November 1994 (50 CFR 651, May 25, 1994); in 1995 the closure was expanded in area and time to include the month of December (50 CFR Part 651, October 30, 1995).

ential DAS counting for all groundfish vessels not participating in the United States/Canada Management Area on Georges Bank. A proposed rule published on July 26, 2006 (NMFS 2006b) created two differential DAS areas: GOM and Southern New England (SNE). For each day that a vessel fishes for any part of a trip in the GOM area, it is charged for two DAS. The purpose of differential DAS counting is to discourage effort in areas where particular fish stocks are not recovering. As such, the differential could be considered a DAS surcharge. A vessel may decide to fish within the surcharge area for various reasons, including profit potential. The surcharge, by reducing profit potential, discourages but does not ban such activity. The objective of the suite of groundfish regulations is to allow groundfish stocks to recover and rebuild to target (maximum sustainable yield [MSY]) biomass levels. This concept of differential DAS counting, referred to as DAS surcharges, is used in this analysis. The analysis presented here draws on data from the years 1994 and 1995, prior to implementation of differential DAS counting.

The Model

Bisack and Sutinen (2006) developed a numerical bio-economic model which allowed the comparison of impacts between closures and a harbor porpoise ITQ system. This model is modified to expand the comparison to alternative DAS reduction policies that include different degrees of spatial and temporal specificity. In this analysis, four versions of fleet behavior were modeled: no regulations (baseline), closures, ITQs, and DAS restrictions. The first three are more fully described in Bisack and Sutinen (2006), but are summarized here.

The bio-economic model incorporated the spatial and temporal patterns of the gillnet fleet's fishing effort, harbor porpoise, and several fish species harvested by the fleet. The temporal stratification was by season (s being winter, summer, or fall), while the spatial stratification was by port group (p being Maine, New Hampshire, northern Massachusetts or southern Massachusetts), from which a vessel operates. Port was synonymous to fishing area;[9] in this fleet, vessels in port-groups fish in non-overlapping areas (figure 1). Vessels are treated as homogeneous within a season-port (N_{sp}), since they face the same price, production conditions, and costs in each season-port combination.[10]

Let q_{isp} represent a vessel's trip production of fish species, i, in season, s, port, p**.** A vessel's production of fish species is modeled at the trip level, which is a function of exogenous season-port dockside prices of the fish species (P_{isp}), fish abundance, and the number of strings hauled. The cost per fishing trip for a vessel operating out of a season-port is a function of effort, $c_{sp}(e_{sp})$. The vessel's total season-port operating cost of effort increases at an increasing rate with an increase in number of trips per vessel, e_{sp}. Stock abundance, cost, and market conditions vary across the season-port combinations available to each vessel.[11]

The total catch of an individual fish species for a season-port is the product of

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[9] The season-port stratification in this analysis is based on the temporal and spatial stratification used to estimate total harbor porpoise bycatch (Bisack 1997). When a port is closed within this analysis, it assumes a fishing area adjacent to the port is closed.
[10] The data show trips are no longer than one day, but the number of trips vessels take per season varies. Examination of vessel characteristic data also shows that vessels are physically alike, which supports the homogeneous assumption within season and port. However, vessels are heterogeneous across season and port strata.
[11] For example, distance to fishing grounds varies across ports, which results in different trip costs due to fuel and time consumption.

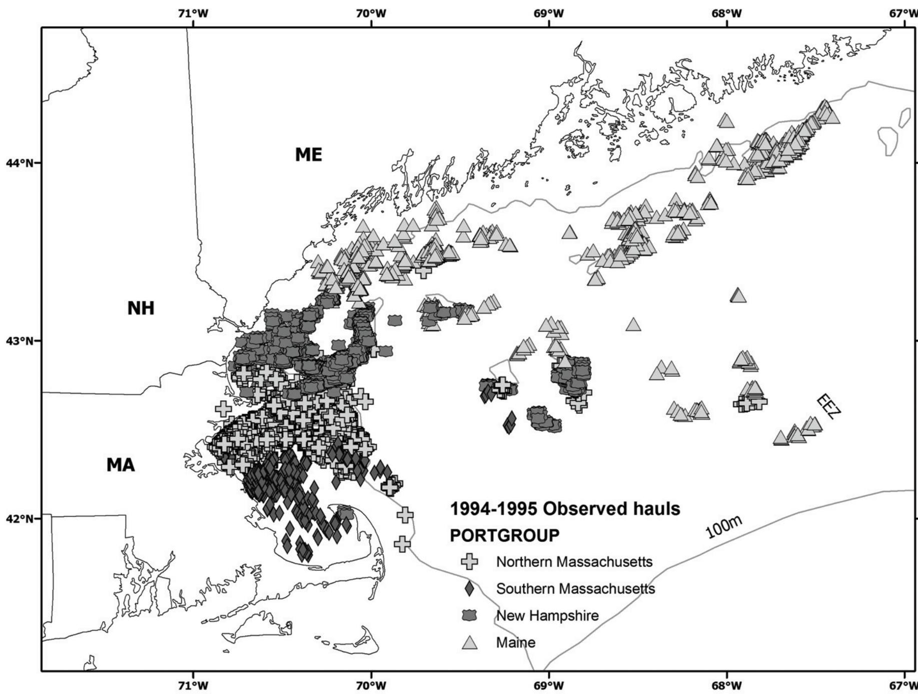

Figure 1. Observed Sink Gillnet Hauls by Port Group (1994 and 1995)
Note: Data show the limited overlap in fishing area between groups.

the number of vessels, trips per vessel, and the vessel's production function. The incidental take of harbor porpoise is calculated similarly. Since managers in the model set a binding quota on the total bycatch of harbor porpoise, the population dynamics relationship is not specified.

For simplicity, I assume there is no natural growth, natural mortality, or recruitment in the exploitable fish populations during each of the fishing seasons and that the fish stock abundance within a year declines by the total harvest by all fleets in each season.[12] In addition to gillnets, several gear types harvest each commercial species; therefore, seasonal stock size (abundance) is equal to the last period's stock size minus the harvest by sink gillnet gear and the harvest of other gear determined exogenously.

Each model predicts equilibrium values for fleet effort, profits, number of season-ports open, and catch rates—in total and as distributed across ports and seasons. The theoretical models cannot by themselves predict or explain the quantitative differences between the programs. For that, a numerical model based on these theoretical constructs was developed. The functional relationships are estimated and presented in Bisack and Sutinen (2006).

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[12] For information on commercial species see: Northeast Fisheries Science Center Reference Document 02-16-Assessment of 20 Northeast Groundfish Stocks through 2001 – A Report of the Groundfish Assessment Review Meeting (GARM). Posted on the web October 25, 2002.

Baseline

In the baseline model, no regulations are imposed on the fishery. Each vessel has a certain number of season-port combinations available from within which they can choose to operate during the course of a normal, unregulated fishing year.[13] Each vessel chooses both the profit-maximizing amount of effort to apply and the season-port combination that maximizes it profits. The fleet maximizes profits by solving the following objective function with respect to effort:

$$\underset{(e_{sp})}{Maximize} \sum_{s} \sum_{p} N_{sp} \left\{ e_{sp} \sum_{i} P_{isp} q_{isp} - c_{sp}(e_{sp}) \right\}. \tag{1}$$

The total effort within a season-port is the product of the number of trips per vessel and the number of vessels. The fleet size in each season-port is historically predetermined.

Closures

To account for the policy of time and area closures to control harbor porpoise bycatch, assume that managers select a set of season-port closures to ensure (or at least maximize the likelihood) that total catch is less than the binding quota. When one or more of the season-port combinations is closed, the total number of season-port combinations available to the fleet is reduced. Vessels formerly fishing in the closed season-ports have to move to other ports (areas) or cease operations. The annual revenue no longer covers all of the annual fixed cost for some of the vessels. Having fewer season-ports in which to operate effectively lowers revenues and/or raises the average total cost of annual effort for those vessels affected by the closure. Since losses are encountered, some vessels are induced to leave the fishery, and total effort (and fishing mortality) is reduced. The reduction in effort results in a reduction in landings in the short run. In summary, compared to the baseline a closure will lead to fewer vessels, less fishing effort, and lower landings of fish in the short run.

Individual Transferable Quotas

To model the fishery under ITQ management, it is assumed managers impose a total annual bycatch quota on harbor porpoise; allocate the total quota among the gillnet vessels, such that each vessel has an individual quota; and allow vessels to freely trade their quotas at any time during the year. The fleet as a whole behaves as if it is attempting to maximize profits over the year, subject to a total harbor porpoise quota (Q):

$$\sum_{s} \sum_{p} N_{sp} e_{sp} q_{hsp} \leq Q. \tag{2}$$

Solving the first-order conditions for this problem with respect to effort shows each vessel operates at an effort level that equates its average revenue of effort to its

[13] Of course, each vessel can choose to operate in only one port (area) for each season of the year.

marginal cost of effort plus a harbor porpoise user cost. The user cost of harbor porpoise is the product of two components: (*i*) the vessel's season-port production rate of harbor porpoise, and (*ii*) the shadow price for a unit of harbor porpoise quota based on fishery values. The market for harbor porpoise quota is assumed perfectly competitive. Therefore, the shadow price is equivalent to the ITQ price of harbor porpoise. Further, the marginal value of one more unit of harbor porpoise quota is equal across all seasons and ports, unless the effort or production rate of harbor porpoise is equal to zero.

Days-at-sea

Managers can impose two types of DAS restrictions to reduce the total harvest of commercial fish species and the bycatch of harbor porpoise: (*i*) a reduction in the number of days a vessel can fish, and (*ii*) a variable surcharge. DAS surcharges are assigned to certain fishing areas to address spatial and for some cases seasonal differences in species abundance. One DAS is equivalent to one fishing trip and is transferable between seasons within a port.

The joint outcomes of alternative DAS reduction scenarios that target either reductions in groundfish landings or harbor porpoise bycatch are examined. Cod (*Gadus morhua*), one of the five major species landed by gillnet gear in the Gulf of Maine, is used as a proxy for all managed groundfish species. That is, although other species are included in the model, this paper only reports cod landings.

Three different DAS measures are examined. In the first DAS program, every vessel receives a reduction in their annual DAS and is called the "DAS Annual Reduction" (DAR) Program. The model examines the degree to which a DAS reduction program designed to limit cod landings may affect harbor porpoise bycatch. The second program, "Differential DAS" implements year-round (DDY) or seasonal (DDS) surcharges to specific fishing areas. Exclusive year-round or seasonal DAS surcharges are applied to specific ports to account for spatial differences in porpoise bycatch. The third type of program combines the DAS annual reduction and the surcharge under the Differential DAS program and is referred to as the "Combined DAS" Program. A Combined DAS year-round (CDY) and seasonal (CDS) program is investigated.

In order to ensure that harvest and bycatch goals are met under the DAS model, the following constraint was added to the baseline model:

$$\sum_{s} N_{sp}\tau_{sp}e_{sp} \leq r\bar{E}_p \quad \tau_{sp} \geq 1, \tag{3}$$

where τ_{sp} is the season port-group surcharge, r is the operating percentage of annual DAS compared to the baseline, and $\bar{E}_p$ is the total optimal port effort (in DAS) under the baseline model. The starting point of the DAS model is the same as the baseline when no management restrictions exist.

Simulation of Programs

Three sources of data were available from the Northeast Fisheries Science Center (NEFSC) Woods Hole, Massachusetts: (*i*) Northeast Fishery Observer Program (NEFOP), (*ii*) the Northeast Commercial Fisheries Database System (NCFDS), and (*iii*) the NEFSC Research Vessel Survey database. The NEFOP program records protected species bycatch, fish catch, gear, and economic data by placing technicians aboard vessels. The NCFDS data are used to estimate total effort (in trips), fish landings, and to calculate dock-side prices of each species. The third data set was used to calculate a minimum population biomass estimate for five Gulf of Maine fish species since fish population estimates were not available for species studied here. Details on the data used within this analysis are in Bisack and Sutinen (2006). This analysis uses data from 1994–95, when management for both the fishery and harbor porpoise bycatch were limited.

The models were run to produce the predicted outcomes and were then compared. Bisack and Sutinen (2006) estimate a total harbor porpoise bycatch of 1,303 animals, under the baseline model.[14] For demonstration purposes, porpoise takes of 507 animals are reported in this paper, similar to PBR in 1995 (*i.e.*, 483), to allow comparisons of DAS management to closure and ITQ management for controlling porpoise bycatch.

Under the closure model, the season-port with the highest bycatch was closed first by setting its fishing effort to zero.[15] The model with this closure is run and estimates of catch and profits were produced. To reach a target of 507 porpoise, three season-ports were shut down to fishing. Specifically, Maine was closed in the fall, and New Hampshire was closed in the fall and winter. To estimate the consequences of the ITQ policy, we set the total harbor porpoise quota (Q) in the ITQ model equal to 507.

Under the "DAS Annual Reduction" (DAR) Program, all ports receive the same annual DAS reduction ($r < 1$). The surcharge was one (*i.e.*, $\tau_{sp} = 1$) for all season-ports, and r was re-adjusted until the porpoise goal of 507 is met. In the "Differential DAS" model, year-round or seasonal DAS surcharges ($\tau_{sp} > 1$) were applied to specific ports to account for spatial differences. There was no reduction in the annual DAS ($r = 1$). A surcharge value of two implied that a vessel fishing one DAS would be charged for two DAS. The data show that Maine and New Hampshire vessels were responsible for 83% of the total take of harbor porpoise bycatch; therefore, these northern ports received the additional surcharge ($\tau_{sp} > 1$). Massachusetts vessels did not receive an additional surcharge ($\tau_{sp} = 1$). The seasonal surcharge was relaxed in the summer when harbor porpoise bycatch was lowest compared to other seasons. The model was run with initial surcharge values for Maine and New Hampshire vessels, and the surcharge was then re-adjusted for subsequent runs until the total porpoise bycatch was reduced to 507.

Under the "combined DAS" program, all vessels received a reduction in the annual DAS compared to the baseline model, and some ports received a DAS surcharge. The overall annual reduction (r) can be set to any level, and the port surcharge (τ_{sp}) can be readjusted until the porpoise take of 507 is met. While a range of annual reduction levels was examined, for illustration purposes, the annual DAS was reduced by 20% for all vessels ($r = 0.80$);[16] with an additional surcharge applied to Maine and New Hampshire. If the annual reduction was low, the results were similar to the differential DAS program and a high annual reduction would have results similar to the DAR program.

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[14] Because of modeling differences, bycatch estimates presented here vary with those in Waring, Quintal, and Swartz (2000).

[15] Two scenarios were investigated in Bisack and Sutinen (2006) for vessel mobility when a port is closed. One scenario assumed vessels cease fishing during the season for which the port is closed, and the other scenario allows vessels to fish in adjacent ports if they are open. For purposes of simplicity, only the first scenario is presented here.

[16] A 20% DAS reduction ($r = 80\%$) was chosen since it was similar to the reduction under groundfish regulations at the time.

Results

Seven programs to reduce the take of harbor porpoise are compared: closures (CL); ITQs; an annual DAS reduction program (DAR); differential DAS year-round or seasonal (DDY or DDS) program; and combined DAS year-round or seasonal (CDY or CDS) program. Impacts on porpoise, profits, and cod landings at the industry, port, and vessel levels are presented by program.

Under the baseline model, where there were no management restrictions, industry profits were $7.2M, harbor porpoise bycatch was 1,302 animals, and 2,507 metric tons of cod were landed by the sink gillnet fishery in the Gulf of Maine. In 1995, this fleet consisted of 200 vessels, which fished approximately 15,350 trips under the baseline model. All management programs achieved the same conservation goal of 507 harbor porpoise (figure 2). Although industry profits were highest under ITQs, the other programs did not perform drastically different compared to the baseline (17–26% reduction). The exception was the DAR program, which reduced industry profits by 46% compared to the baseline.

While all the programs had the same impact on harbor porpoise, the programs can be separated into three groups based on reductions in cod landings and profits. Group one had reductions in cod landings between 29–36% (CL, ITQ, DDS, and CDS), while the second group experienced reductions between 46–52% (DDY and CDY) (figure 3). The DAR program was the outlier, group three, with cod landings reduced by 60%. Group three had the greatest reduction in industry profits compared to the other two groups. In general, the DAS programs with the year-round surcharges (DDY and CDY), capture the seasonal patterns of harbor porpoise bycatch with additional restrictions on cod landings. The program selection decision may be based on the goals of the cod management plan. That is, if large reductions in cod landings are necessary to achieve the biological goals of cod, then the DAS year-round (DDY and CDY) or DAR programs are likely to be preferred.

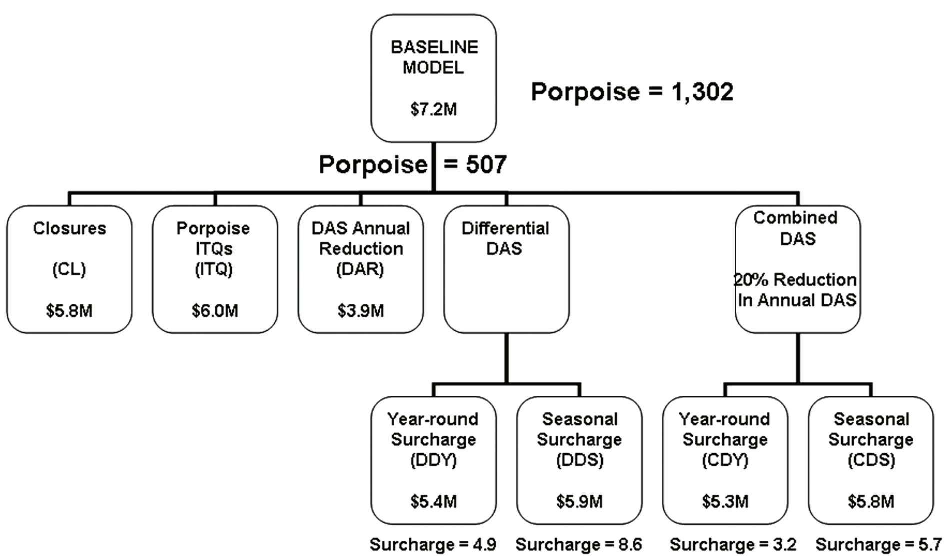

Figure 2. Total Take of Harbor Porpoise, Industry Profits ($1,000,000), and DAS Surcharge for each Management Program

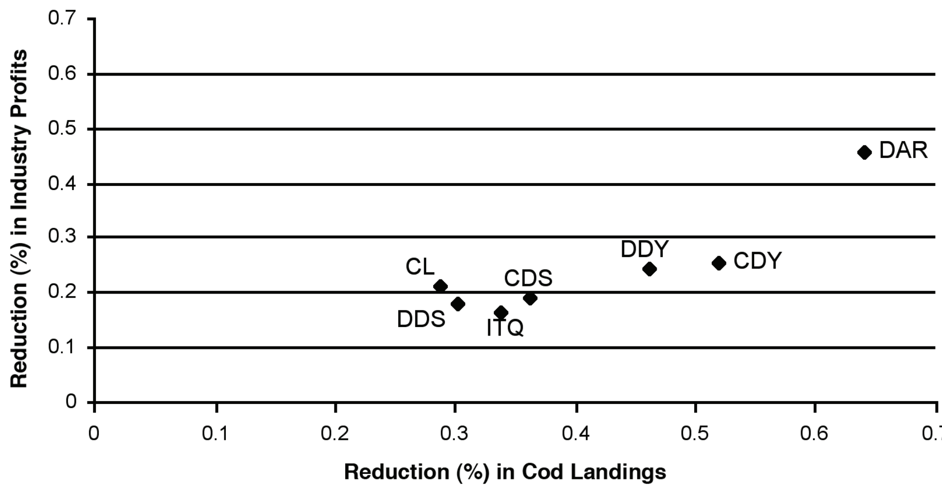

Figure 3. Reduction in Industry Profits versus Cod Landings under Alternative Management Programs Compared to the Baseline Model

Note: CL=Closure, ITQ=Harbor Porpoise ITQs, DAR=DAS Annual Reduction, DDS and DDY=Differential DAS Seasonal and Year-round, CDS and CDY=Combined DAS Seasonal and Year-round.

Although profit reductions are slightly higher under the combined DAS seasonal (CDS) program, the CDS program has even lower fishing effort levels and a higher reduction in cod landings compared to ITQs. Fishing effort for group one (CL, ITQ, DDS, and CDS) was reduced between 18–31%, while group two (DDY and CDY) reduced fishing effort by 40% compared to the baseline. The DAR program, group three, reduced effort by 67%. Effort and cod reductions are strongly correlated with profit reductions.

Surcharge values were adjusted to reduce the total take of harbor porpoise in the gillnet fishery. Surcharge values ranged between 3.2 and 8.6 under the differential (DDY and DDS) and combined (CDY and CDS) DAS programs (figure 2).[17] A surcharge of 3.2 implied Maine and New Hampshire vessels were charged 3.2 DAS for fishing 1 DAS, while Massachusetts vessels received no surcharge. Porpoise take rates were significantly lower in northern and southern Massachusetts compared to the other ports. In general, seasonal surcharges reduce the majority of the porpoise take in seasons with high bycatch rates (DDS and CDS), while programs with year-round surcharges (DDY and CDY) shift some of the porpoise reductions to seasons with lower bycatch rates. For this reason, year-round surcharge values are lower than seasonal surcharge values. Additionally, surcharge values are lower under the combined (CDY and CDS) compared to the differential (DDY and DDS) DAS programs. Massachusetts vessels are forced to reduce their porpoise bycatch under the combined DAS (CDY and CDS) programs.

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[17] The DAS surcharge in this example is much higher than the DAS surcharge currently in place under the multi-species FMP DAS program. For ease of implementation, two DAS surcharge levels are used for groundfish. The actual surcharge tends to be low (*i.e.*, 2 in GOM). Twelve groundfish species are being managed under the same DAS surcharge. The species that requires the largest reduction is likely to be the binding constraint, which then determines the surcharge (personal communication, John Walden, NEFSC).

Maine and New Hampshire ports had larger reductions in porpoise, port profits, and cod landings compared to Massachusetts ports under all policies, with the exception of the DAS annual reduction (DAR) program (table 1). Compared to the year-round surcharge (DDY and CDY) programs, the seasonal (DDS and CDS) programs provide economic relief to Maine and New Hampshire vessels by allowing them to increase fishing effort in the summer season when porpoise bycatch rates are low, which results in an increase in port profits. The ITQ and the combined programs (CDY and CDS) force Massachusetts ports to bear some of the burden of reducing porpoise bycatch.

If one assumed profits were a proxy for a port's preference for a program, both Maine and New Hampshire would likely prefer the ITQ, DAS seasonal (DDS and CDS), and the DAR programs since profit reductions are similar (39-46%) compared to the baseline (figure 4). Neither Maine nor New Hampshire would choose the year-round surcharge programs (CDY and DDY), since profit reductions were much greater (59-63%). However, Maine would prefer the closure (CL), while New Hampshire would certainly not prefer the closure (CL). If the preferences of Massachusetts ports are also considered, the closure (CL) and the differential DAS programs (DDY and DDS) would be chosen over the combined DAS (CDY and CDS) and the DAS annual reduction (DAR) program (table 1).

In summary, by examining the impacts of the various programs based on industry profits and porpoise take, one might eliminate the DAR program (figure 3). Yet, by examining the impact on ports we see Massachusetts would not consider the

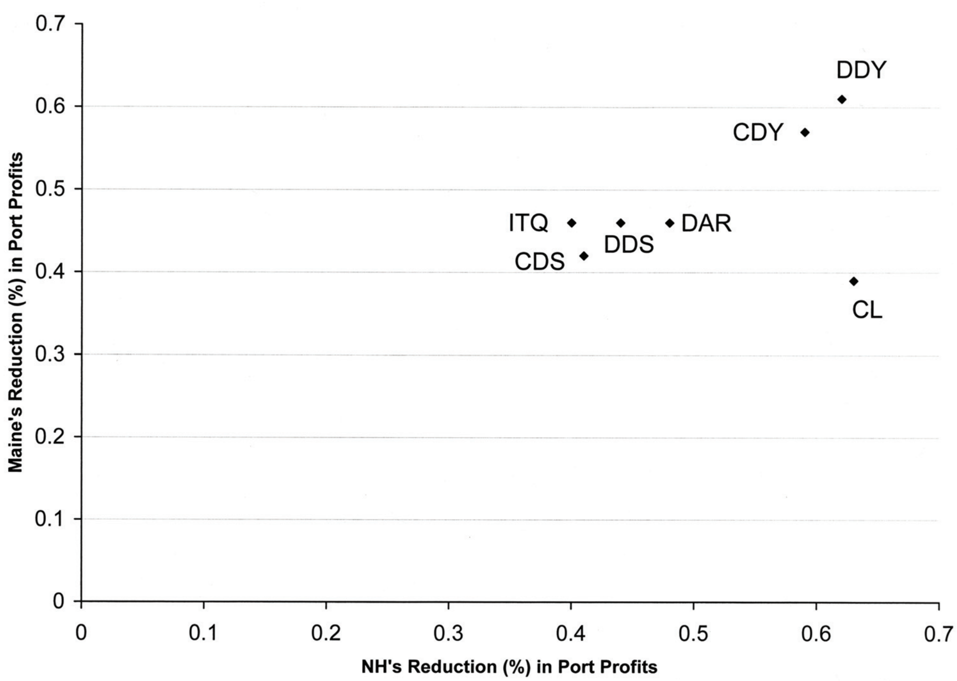

Figure 4. Reduction in Port Profits in Maine versus New Hampshire under Alternative Management Programs Compared to the Baseline Model

Note: CL=Closure, ITQ=Harbor Porpoise ITQs, DAR=DAS Annual Reduction, DDS and DDY=Differential DAS Seasonal and Year-round, CDS and CDY=Combined DAS Seasonal and Year-round.

Table 1
Reduction in Porpoise (animals), Industry Profits ($1,000), a Vessel's Profit ($1,000), and Cod Landings (tonnes) by Management Program Compared to the Baseline by Port

			Reduction (%) Compared to Baseline						
					DAS	Differential DAS		Combined DAS	
			Closure	ITQ	Annual Reduction	Yr-rnd	Season	Yr-rnd	Season
Port		Base	CL	ITQ	DAR	DDY	DDS	CDY	CDS
ME*	Porpoise	509	47	65	56	67	68	62	64
	Port Profit	1,244	39	40	46	61	46	57	42
	Vess. Profit	41.0	45	46	41	55	52	50	48
	Cod	744	59	51	64	78	47	75	45
NH	Porpoise	568	98	77	70	80	79	78	76
	Port Profit	1,673	63	40	48	62	44	59	41
	Vess. Profit	62.0	67	40	49	64	47	61	44
	Cod	740	37	52	64	76	54	75	53
N.MA	Porpoise	127	0	9	65	0	0	20	20
	Port Profits	2,804	0	1	47	0	0	4	4
	Vess. Profits	42.7	0	1	45	0	0	4	4
	Cod	675	0	7	56	0	0	18	18
S.MA	Porpoise	98	0	14	34	0	0	9	9
	Port Profits	1,497	0	1	42	0	0	4	4
	Vess. Profits	38.7	0	2	35	0	0	3	3
	Cod	348	0	8	53	0	0	17	17

*ME=Maine, NH=New Hampshire, N.MA = northern Massachusetts, S.MA=southern Massachusetts.

DAR program, but Maine and New Hampshire would (figure 4). New Hampshire would not consider closures (CL), but Massachusetts and Maine would. However, allowing each port to choose its own program is not typically allowed.[18]

Discussion

Industry, port, and vessel profits were simulated under seven different management programs for the Gulf of Maine sink gillnet fishery designed to reduce harbor porpoise bycatch by 61%. All programs met the same harbor porpoise conservation objective, although cod management outcomes differ. Industry profits were greatest under ITQs; however, results under other programs were not greatly different, with the exception of the DAR program. If cod reductions are considered, managers may choose the differential and combined DAS year-round (DDY and CDY) programs over closures, ITQs, and DAS seasonal (DDS and CDS) programs. Thus, several regulatory programs for marine mammal protection may achieve the same conservation outcome with modest differences in profits, but large differences in cod landings.

The results illustrated the inter-relationships between fisheries and marine mammal management actions at the industry level. At the port level, distributional impacts may influence policy preferences. For example, northern ports would prefer the DAS seasonal (DDS and CDS) and annual reduction (DAR) programs over the DAS year-round (DDY and CDY) programs. Massachusetts ports would certainly not prefer the DAS annual reduction (DAR) program, which provides economic relief to northern ports at their cost. Separate management policies for each port would be administratively difficult and would not achieve the porpoise take reduction goals. However, these differences must be recognized because they may lead to difficulties in reaching consensus on management actions.

The current differential DAS surcharges under the Northeast Multi-species Fisheries Management Plan are designed to reduce fish landings and are year-round;[19] they address spatial differences in species abundance. Such fisheries management actions could also reduce harbor porpoise bycatch. However, the year-round nature of this effort reduction is likely to result in smaller profits than if a more targeted seasonal approach were used. The use of seasonal surcharges on DAS provides a signal to fishers on the differences in harbor porpoise bycatch across seasons. They also allow fishers to adapt to inter-annual differences in cod availability and prices, thus allowing for higher profits than under broader DAS reductions.

These results assumed that DAS are non-transferable between ports; however, existing regulations allow leasing of DAS between vessels.[20] Transferability within ports or between seasons may change these results, depending on the transfer/leasing. For example, a within-port DAS transfer from winter to summer would reduce porpoise bycatch. The greatest concern, from a protected species perspective, is for the cases where porpoise bycatch could increase. This could occur if DAS were transferred between ports or seasons when the receiving port/season has a higher bycatch rate than the originating port/season.

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[18] Because vessels are of a homogeneous nature within a season port, vessel program preferences are similar to the patterns identified at the port level (table 1).

[19] DAS programs are targeting yellowtail flounder mortality reductions. In addition to DAS reductions, vessel buyout programs and trip limits have been implemented (NEFMC 2006).

[20] Under groundfish management, a leasing option was established under Amendment 13. There are four classes of sink gillnet vessels based on engine horsepower and vessel length. Leasing is downward compatible. A vessel can only lease DAS from vessels within its own class or larger.

The challenges that emanate from these results are twofold. First, separate regulations are being developed for different resources accessed by the same communities. As the results show, MMPA guidelines would not differentiate between the seven programs; however, an economist following E.O. 12866 guidelines based on industry profits would recommend the closure, ITQ, and DAS seasonal programs over the other programs. But if the MSFCMA, RFA, and NS 8 are considered independently or collectively, program preferences would differ. Incorporating the goals of these Acts simultaneously into our empirical models to assist in managing our natural resources is a complex task. The challenge is to develop regulations that are designed to achieve fish and protected species goals simultaneously. Additional empirical research could lead us away from single to multi-species and eventually to ecosystems-based management. This paper suggests that although this may be difficult, it is achievable.

Second, PBR could be allocated across the fishery based on biological and economic principles as demonstrated in this article. Seven programs achieved PBR with small differences in profits at the industry level, but examination of the disaggregated results reveals striking differences between ports. How should a program be selected? While various Acts provide some guidance on how to allocate impacts at the industry, port, community, and vessel levels, the guidance is incomplete.

Under the appropriate set of policy instruments and management incentives, industry, scientists, and administrators can be compelled to search for and discover the combination of tools and instruments that best meets economic, social, and biological goals. Incentives can induce fishers to employ bycatch reduction devices, to make conservation investments, or to undertake practices that may reduce the adverse impacts of fishing (Grafton *et al.* 2006). For example, there are individual non-transferable bycatch quotas used for dolphins in the international tuna-fishery in the eastern tropical Pacific (Anonymous 2000; Hall 1998). Dolphin bycatch quotas are assigned to individual vessels, but trade between vessels is prohibited. Tuna boat operators have the incentive to create new fishing practices that avoid dolphins. Such a profitable fishery can also offset the cost of an observer for the required 100% observer coverage. Although the property rights are not complete, rights can be reassigned or forfeited. Harvesters may receive a price premium from certification programs which endorse fishing practices that also support conservation goals.

Determining the set of input and output controls and technical measures that may be "optimal" to meet agency objectives for a particular fishery is a fundamental challenge. In the Northeast, groundfish regulations implement all three approaches: DAS (input), trip limits (output), and mesh restrictions (technical measure). When considering porpoise bycatch in the Northeast, a harbor porpoise ITQ program may be economically more efficient than closures; however, there are practical issues of implementation, in particular, enforcement. For a non-marketed species, such as harbor porpoise that is not landed at the dock, at-sea monitoring and/or enforcement is necessary.[21] Yet, porpoise takes are rare events for this particular gear type, and the chance of detecting a porpoise ITQ violation at sea is extremely low, making ITQ monitoring difficult.

In 2004, harbor porpoise bycatch increased to levels above PBR and was again a concern in 2007 (Waring *et al.* 2006). To reduce the porpoise take below PBR (again), it seems clear that new approaches are necessary. The New England Fisheries Management Council is considering fisheries management alternatives for

[21] The NEFOP samples approximately 5% of the sink gillnet's total effort and is not likely to increase sampling in the near future. In addition, unlike the ETP tuna fishery, sink gillnet profits would not be large enough to offset the cost of an observer program.

groundfish through the Amendment 16 scoping process.[22] As the various systems to control groundfish are considered and evaluated, it would be prudent to incorporate marine mammal and sea turtle bycatch goals into the system. DAS programs have been implemented within the Northeast fisheries to achieve fisheries management objectives.[23] Extending the current DAS program to include a seasonal component may be a stepping stone to additional approaches that protect marine mammals and address social impacts while achieving fisheries management goals.

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[22] One proposal considered was a groundfish point system that has characteristics similar to ITQs. The proposal suggested allocating points to each groundfish stock with different point values based on the available groundfish TAC and its fishing status. Points could be adjusted throughout the year. See meeting materials for the January 18, 2007 Multispecies Meeting in Mansfield, MA, at www.nefmc.org/nemulti/index.html

[23] Although this is not estimated here, if we assume enforcement costs of monitoring DAS is lower than ITQ to control harbor porpoise bycatch, net national benefits derived under a DAS program may be higher compared to an ITQ program.

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