

TRADABLE FISHING EFFORT IN THE NEW ENGLAND GROUND FISH FISHERY

BY

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## ABSTRACT

Management of the New England groundfish fishery has become a complex and often confusing web of controls that regulate the fishery, in large part, by making vessels and fisherman inefficient. Government-induced incentives for investment in the fishery have led to fleet over-capitalization. Initial allocations of Days-At-Sea were ad-hoc, and subsequent DAS reductions have left year-round groundfishing vessels with limited time to ply their trade. DAS allocations have also created a vast source of fishing effort that can flow into the fishery at the first sign of industry recovery. These have combined to create a fleet that possesses, should all permitted vessels commence fishing, fishing capacity vastly in excess of the carrying capacity of the resource. Many, if not most, of the complicated fishery regulations currently in use have been enacted to deal with affects of this over-capacity. A period of resource decline has followed, as too many vessels compete for too few fish.

The primary focus of this research is the development of a model market for tradable units of nominal fishing effort. Tradable fishing effort is less studied and less understood than tradable fish quota's, which are rejected due to the costs and difficulties associated with monitoring and enforcement of the multi-species groundfish fishery. Quality-adjusted nominal effort units, which account for the differences between nominal effort units of vessels of differing sizes, are used to determine the point of zero net excess supply or demand in the nominal effort market. The objective of the market is to allow for increases in fleet efficiency through market trades, to simplify groundfish fishery regulation, and to allow policy makers a tool for the removal of excessive and unutilized nominal fishing effort.

Modeling results indicate that nominal effort trades will result in substantial increases in fishery output that, if unconstrained, could potentially exceed the carrying capacity of the resource.

Several options for reducing this affect are explored. A decrease in existing nominal fishing effort of roughly 60% prior to market trades corresponds to a conservation-neutral market for nominal fishing effort.

## ACKNOWLEDGMENTS

I am primarily indebted to my thesis advisor, Rusty Russell. The idea for this thesis stemmed from a minor paper assigned during Rusty's Environmental Economics and Policy course, ES-135. Since agreeing to be my advisor, Rusty stuck by me and in so doing demonstrated a remarkable confidence in my abilities...confidence was probably not always warranted. There were many times when I knew that Rusty felt he was allowing me to get off course, but in getting lost I was sometimes able to find new vantage points on the issues that interested me most. I cannot thank Rusty enough for the freedom to pursue, often against his better judgement, a thesis closely aligned to the changes that I perceived in the New England groundfish fishery.

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Eric Thunberg at the Northeast Fisheries Science Center arranged for my internship and taught me most of what I know about fishing capacity, modeling, and statistical approaches. He had the patience and selflessness to help me on a weekly and sometimes daily basis when there was absolutely nothing in it for him. I'm still don't completely understand why he helped me as much as he did, but the fact remains that without Eric, there would be no thesis...and I would be in a whole heap of trouble with Rusty and Harold. I wish there were some way I could repay him for his efforts, because "thank you" does not seem substantial enough.

Prof. David Weil was extremely kind in offering his advice and opinions on how to best approach the market-related aspects of this thesis. Without his council, I would have had no quantitative basis for trade predictions and no predicted changes in fishery output. In short, I would have only a half-a-thesis. Again, I have no idea why Prof. Weil so selflessly agreed to assist me, but I'm glad that he did.

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## SECTION 1: HISTORY OF MANAGEMENT IN THE NEW ENGLAND GROUND FISH FISHERY

### 1.0 Introduction

The northwest Atlantic has provided fertile groundfish fishing grounds for centuries. Basque fisherman were known to fish the waters off Newfoundland, Nova Scotia and northeastern Canada for centuries before these areas were discovered by the explorers of the fifteenth and sixteenth centuries (Kurlansky 1997). Since this time, the northwestern Atlantic Ocean has yielded a bountiful natural resource that has, in recent times, strained under the weight of increased exploitation.

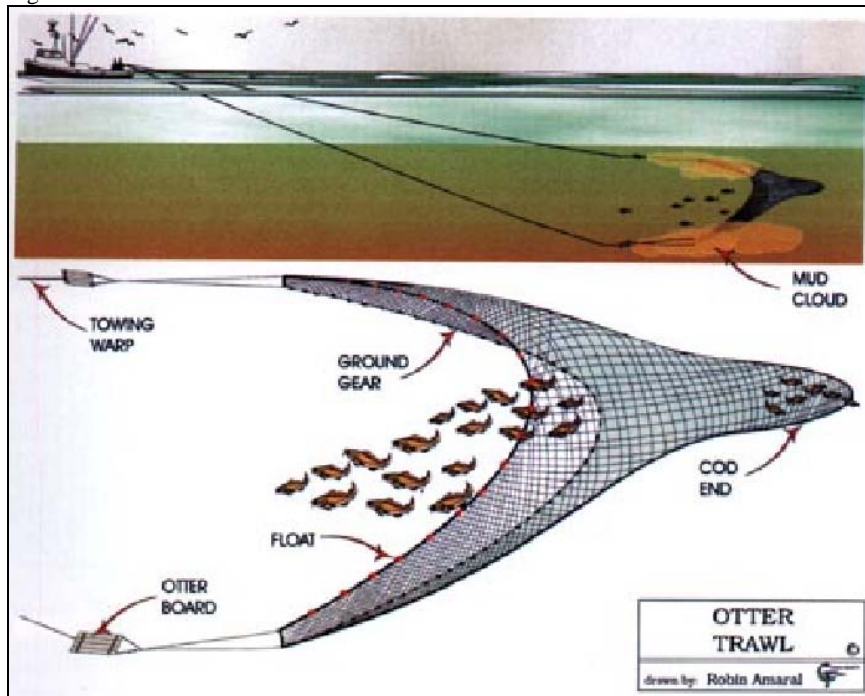
The history of groundfish fishery management in New England is traced to provide background on management structures and concepts relevant to the development of this thesis. Two themes emerge from this portion of the investigation. The first is that the complex regulatory structure that has evolved in New England has not only failed to prevent over fishing of the valuable groundfish resource, but has created a vastly inefficient fishing industry. The second theme is that regulatory decisions made by fisheries managers and Congress have caused fisherman to invest more money in fishing capital than would otherwise have been necessary, resulting in an excessively large groundfish fishing fleet.

### 1.1 Multi-National Management

Fishery regulation first became an issue of regional concern shortly after the 1905 introduction of the otter trawl in American waters (Jensen 1972). Before this time, the groundfish fishery was prosecuted exclusively by hook and line, which limited total fishing effort to the sheer number of fish a fisherman could haul. Hooks targeted only large, mature fish and any smaller fish hooked

were immediately returned to sea. The introduction of the otter trawl changed the very nature of this fishery by introducing a technology that had the potential to outpace nature's resilience.

Fig 1.1: Otter trawl net



The North American Council on Fisheries Investigations (NACFI), in existence from 1920 to 1938, was the first international organization charged with management of northwest Atlantic fisheries. Their only significant contribution to fisheries management was the creation of the Northwest Atlantic statistical areas. These areas were created on the basis of natural ecological divisions and what was known of the fish populations in each area at the time, and are still in use today (Jensen 1972, Matykiewicz 1982).

In 1949 the International Commission for the Northwest Atlantic Fisheries (ICNAF) succeeded the NACFI. This organization was formed for the “investigation, protection and conservation of the fisheries of the Northwest Atlantic Ocean, in order to make possible the maintenance of a

maximum sustained catch from those fisheries.” ICNAF covered the entire northwest Atlantic from the west coast of Greenland, Labrador, Newfoundland, Nova Scotia, and New England as far south as Rhode Island. Initially consisted of 14 nations: Canada, Denmark, France, West Germany, Iceland, Italy, Norway, Poland, Portugal, Romania, Spain, U.S.S.R., United Kingdom, and the United States. The organization was mainly concerned with minimizing the destruction of young fish in otter trawl nets. Their experiments led U. S. fishery managers to institute a minimum mesh size of 4.5 inches in 1953. Mesh size restrictions continued as the fundamental component of fishery management through the 1970’s, but while minimum mesh sizes steadily increased, the abundance of cod, haddock, and yellowtail flounder steadily declined.

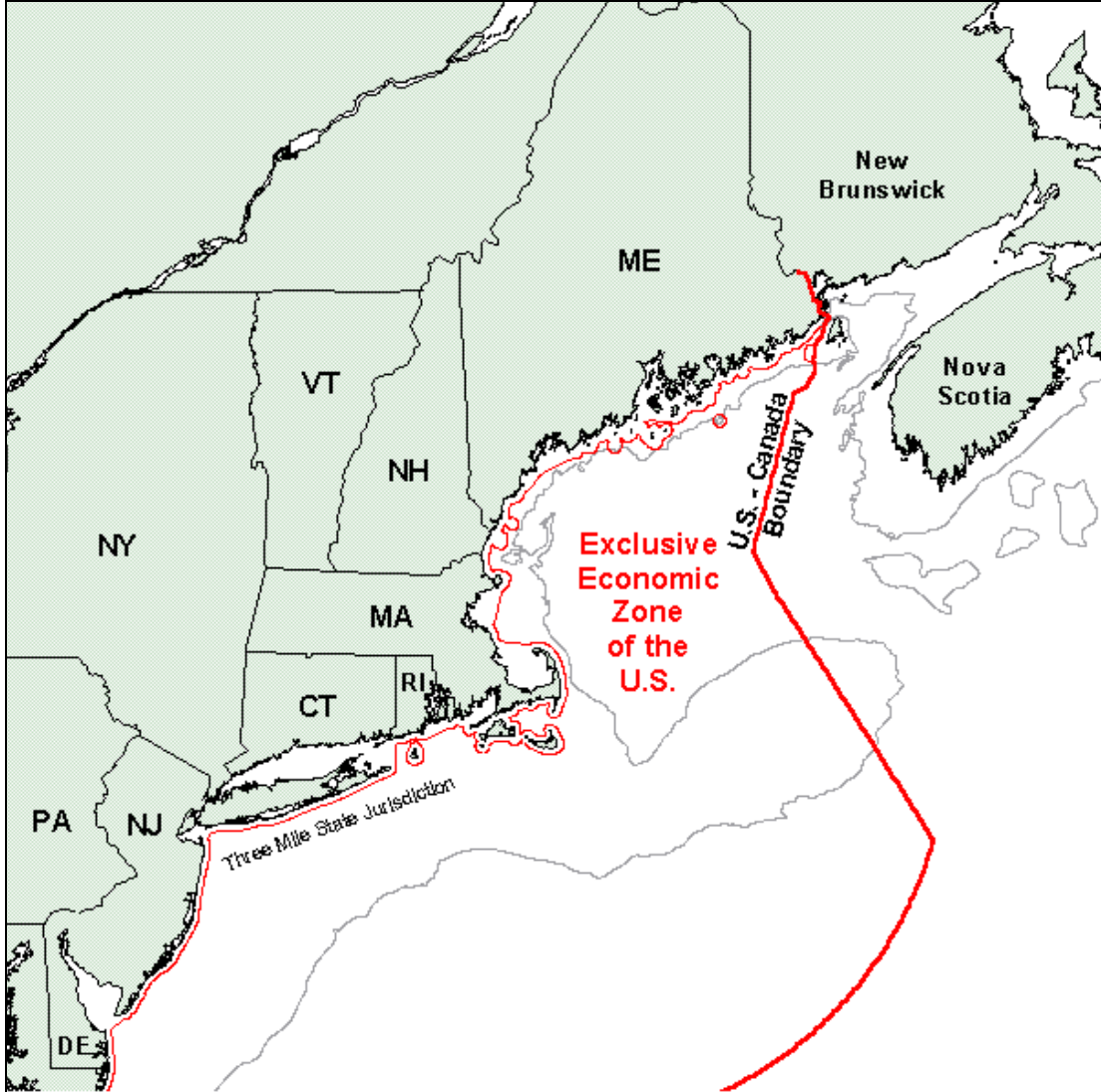
As a result of these declines, between 1945 and 1970 the federal government provided increasing levels of assistance to the fishing industry. The New England region in particular did not have a history of producing a good return on fisheries investment, and long-term loans were difficult for individual fisherman to obtain. In 1956 the U.S. government began the Fishery Loan Program, which offered low-interest, federally guaranteed loans to fishermen. In 1965 the Fishing Vessel Capital Construction Fund (CCF) was instituted. The CCF allows vessel owners to put a portion of their pre-tax income into a capital construction fund, and it is still in use today. Many of the vessels still fishing in New England waters were built with money from these programs.

## 1.2 Federal Management

In 1976 Congress passed the Fisheries Conservation and Management Act (FCMA)<sup>1</sup>, primarily to address foreign fishing in U. S. waters. The FCMA prohibited foreign fishing within the U.S. territorial sea, which was defined at that time as waters out to 12 miles from the U. S. coast. This

was soon expanded to include the U. S. Exclusive Economic Zone (EEZ), which covers waters from 3 to 200 miles off the U.S. coast<sup>2</sup>.

Fig 1.2: Map of Exclusive Economic Zone of the U. S.



source: New England Fisheries Management Council

The FCMA listed 10 National Standards for fisheries management, which continue to guide policy makers in creating fishery regulations (see Appendix C). Eight regional fisheries

<sup>1</sup> Later called the Magnuson Fisheries Conservation and Management Act, then the Magnuson-Stevens Fisheries Conservation and Management Act. The 1996 re-authorization of the Act is called the Sustainable Fisheries Act (SFA).

<sup>2</sup> Waters from 0 to 3 miles off shore, called “state waters,” are managed by the coastal state.

management councils were created, each responsible for regulating the federal fisheries within their jurisdiction. The councils are made up of representatives from each coastal state in the region, the regional National Marine Fisheries Service administrator, and selected members-at-large equal in number to twice the total number of member states. Additional non-voting members include the regional Director of the Fish and Wildlife Service, the Commander of the regional Coast Guard District, and one member of the Department of State. They are charged with assessing available scientific data and creating fishery management plans (FMP's), which are forwarded to the NMFS Regional Administrator for authorization. The Regional Administrator has the option of authorizing the FMP as is, altering it prior to implementation, or rejecting it altogether and implementing his or her own management plan. Therefore, these regional councils are advisory in nature and have no official regulatory authority.

### 1.3 The Quota Management Period

The New England Fisheries Management Council (NEFMC) managed the groundfish fishery between 1977 and 1982 by instituting quotas for each of the three principle groundfish species (cod, haddock and yellowtail flounder). These quotas were based on ICNAF records that soon proved to be unreliable. In 1977, the first year of regulation by the NEFMC, fishing for the three primary groundfish species was suspended within three months of the season opening when all the quotas were exceeded (Hennessey and Healey 2000). Smaller fishing vessels that typically fish only in the summers claimed that this was unfair because they had not yet had the opportunity to go fishing. Other fisherman stated that the quotas favored fisherman who traditionally fished close to their homeports. Regulations intended to apply evenly to all fisherman were shown to have powerful distributional impacts. By 1978, the species quotas were scrapped in favor of "vessel class" quotas based on the size of fishing vessels and their typical gear used. Distinctions of "vessel class" were arbitrary, and nearly every vessel appealed for it's

own class due to special circumstances unique to each geographic area, gear type, fishing pattern or target species. The additional complexity of separate quotas invited noncompliance, as vessels would, for example, catch twice their allocation while claiming different gear types and access to different quotas (2000). Despite these problems, the quotas were in effect until 1982.

During the early 1980's fisherman utilized the Capital Construction Fund extensively to build larger, more efficient vessels. In fact, NMFS estimates that between 1977 and 1992, the CCF and other government-sponsored programs helped increase the number of fishing vessels in New England by 80%, while the number of fisherman increased 140% (NMFS 1995). Furthermore, Hennessey and Healey observe that "the Tax Reform Act of 1980 had a dramatic effect on fleet capitalization as wealthy fishers and investors from outside the industry began to buy boats for tax relief" (2000). The Tax Reform Act was amended in 1986, but during the 1980's its influence in building the size of the fishing fleet "appears to have been considerable" (2000).

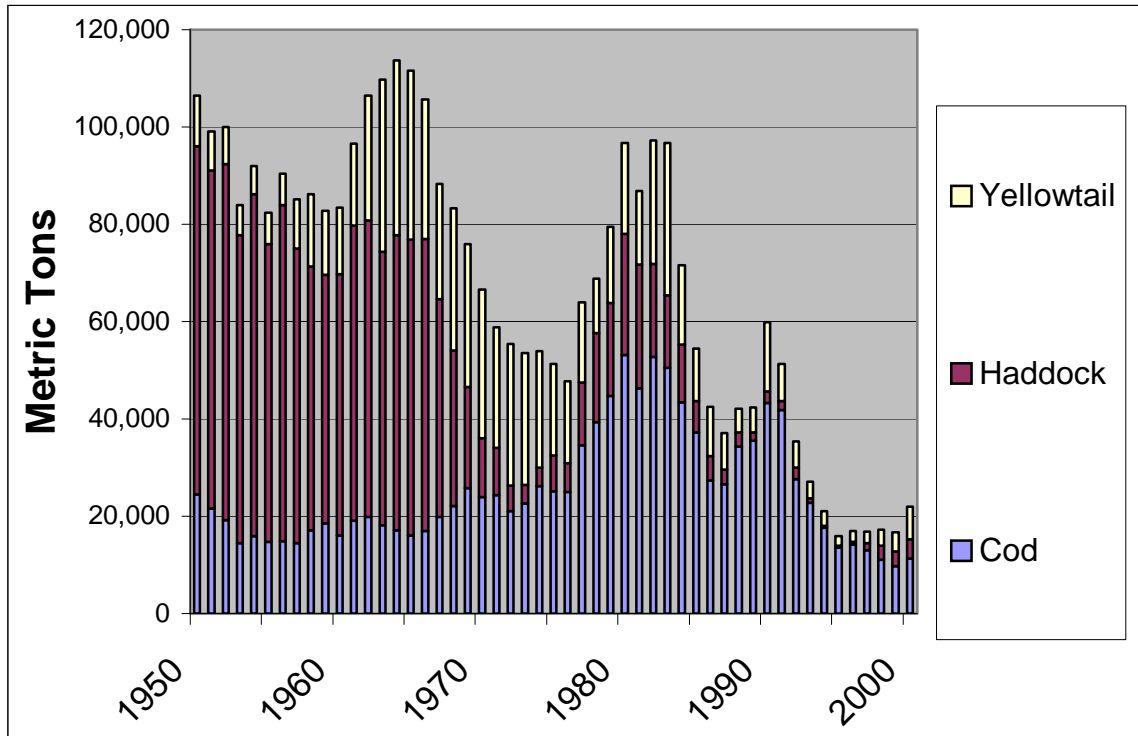
#### 1.4 The Indirect Management Period

Between 1982 and 1992, quota management was suspended and a series of measures focusing on mesh size restriction were implemented. Net mesh size varied for different geographic areas, allowing fisherman to jump from one regulatory area to another on the same fishing trip and making enforcement of mesh sized virtually impossible. Minimum fish (species) sizes were instituted to try and negate the incentive for illegal fishing, the rationale being that fishing with small mesh nets would not be necessary if smaller fish were not legal to land. These minimum fish sizes, however, were also area-specific, and with no means of proving where species were caught they too were largely unenforceable.

In 1986 the NEFMC implemented the Comprehensive Groundfish FMP, which continues to serve as the Groundfish FMP to this day. The only significant change that this signaled was the use of biological targets for the removal of juvenile fish. The Groundfish FMP also expanded the definition of groundfish to include more species. There were still no direct controls on fishing effort included in this plan. The groundfish fishery remained open to access, and vessel permitting was unrestricted (Wang 362).

In November of 1986, the World Court at The Hague established a boundary between the U.S. and Canadian Exclusive Economic Zones. The practical impact of this ruling was that the fishing effort that had previously been dispersed across both U.S. and Canadian waters was then condensed to only U.S. waters (Wang 362). Meanwhile, fish stocks continued to show signs of decline. By June of 1988, the Groundfish Monitoring Committee of the NEFMC reported that stock levels of cod, haddock and yellowtail flounder were at historic lows (Hennessey and Healey 2000).

Fig 1.3: Landings of principle groundfish, 1950-2000



source: NMFS Office of Statistics

As the health of the cod, haddock and yellowtail stocks continued to show no improvement, the need for regulation increased. In 1989, the NEFMC promulgated 602 individual management guidelines requiring specified overfishing definitions for every fish stock. The guidelines directed the Council to design rebuilding programs for all stocks classified overfished by these guidelines. The Council adopted Amendment 4 to the Groundfish FMP in 1991 as a direct response to the “602 guidelines.” Under Amendment 4, cod, haddock and yellowtail flounder were deemed overfished, but the amendment lacked any mention of a stock rebuilding they required (Wang 1997).

That same year, the Conservation Law Foundation (CLF), a Boston-based nonprofit environmental advocacy group, brought suit against NMFS (and others) for implementing an amendment that did not prevent the overfishing of cod, haddock and yellowtail flounder stocks in

accordance with the 602 published requirements. A consent decree was reached between the CLF and NMFS in late 1993 under which the NMFS agreed to reduce groundfish fishing mortality by 50% over a 5 year period (Hennessey and Healey 2000).

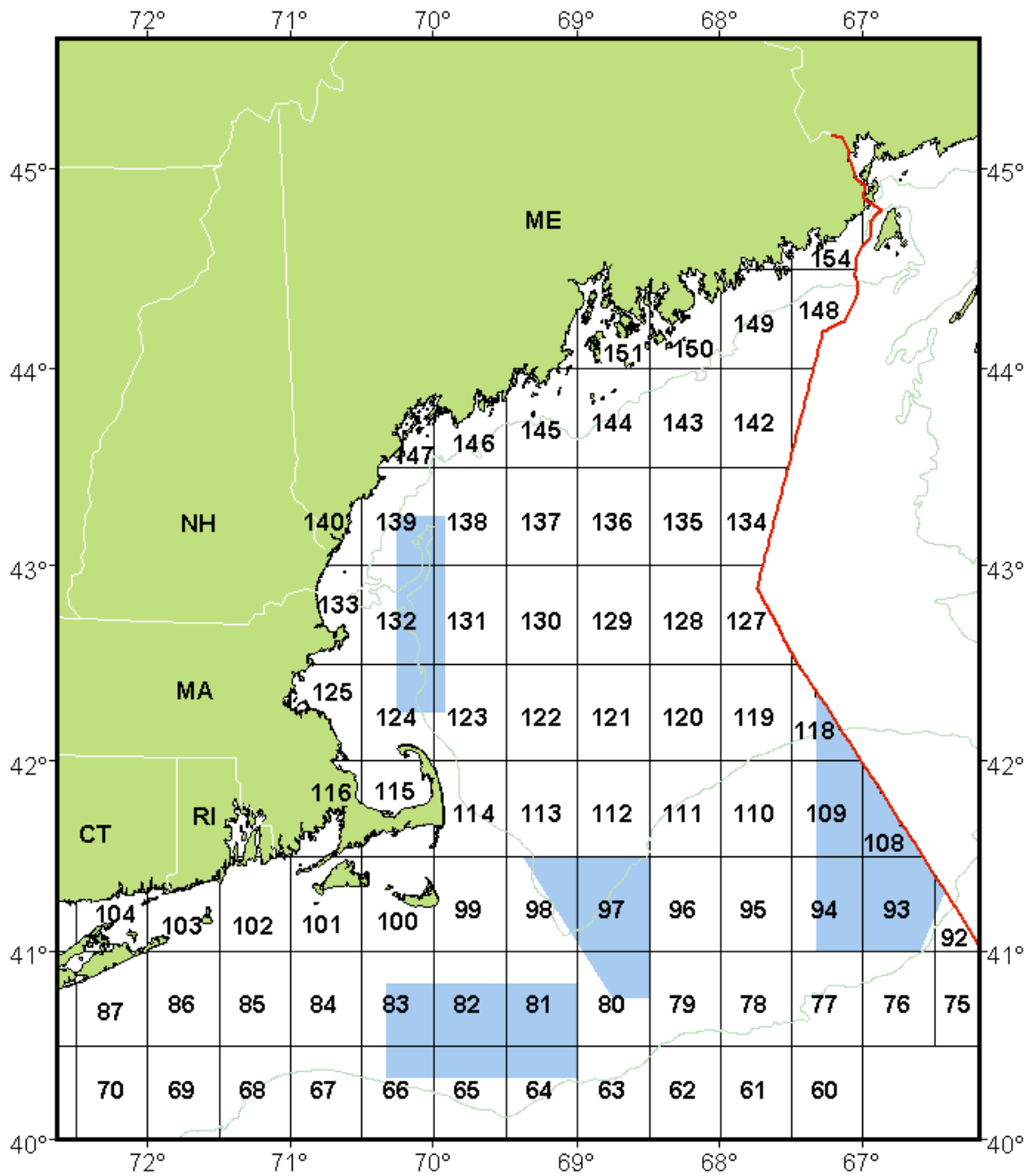
### 1.5 The Limited Access Period

Amendment 5, passed in 1994, was intended to eliminate the overfished condition of cod, haddock and yellowtail flounder stocks. Amendment 5 changed the basis of groundfish management once again, shifting from a focus on mesh size to an emphasis on fishing effort controls, the use of wide area closures for spawning groundfish, and a complicated series of landing quotas. Amendment 5 included the creation of “limited access” groundfish permits, which were issued to all vessels with a documented history of groundfish landings in New England. A moratorium on new groundfish permits was instituted, and effort quotas in the form of allocated vessel days-at-sea (DAS) were created. Once again, mesh size requirements for vessels targeting groundfish were raised. Additional measures included mandatory reporting of landings by vessels and fish dealers (1997). Groundfish permits were permanently and irrevocably attached to individual vessels, and a moratorium on vessel upgrades, including length and horsepower increases, was instituted. Vessels could be replaced, but they could only retain the groundfish permit if the new vessel was smaller and of less horsepower than the vessel it was replacing.

In December 1994, an emergency action by the Council in response to the Conservation Law Foundation lawsuit permanently closed three previously seasonal closure areas on George’s Bank to all fishing vessels capable of catching groundfish. These areas accounted for as much as 50% of the historical fishing grounds. Their closure had the unintended affect of focusing an equal amount of fishing effort on roughly half the geographic area. Pressures on the fish stocks found

outside the closed areas increased dramatically. The reduction of available fishing area also provided an incentive for fisherman to fish areas that were previously deemed unfishable, usually due to their rocky or “hard” bottom. New technologies such as large “rockhopper” tires on fishing nets were employed to gain access to these rocky areas.

Fig 1.4: Map of four year-round closed areas (shaded)



Source: New England Fisheries Management Council

In August of 1994 NMFS scientists issued a Special Advisory, warning that the yellowtail flounder stock had collapsed and the cod stock was in imminent danger of collapsing<sup>3</sup>. They declared that Amendment 5's measures "were clearly inadequate to prevent the collapse of cod or allow the rebuilding of yellowtail flounder" (NMFS 1994). The scientists recommended that fishing mortality for the two species should "approach zero" (Hennessey and Healey 2000). The report was widely ignored.

In early 1996, the NEFMC passed Amendment 7, which aimed to reduce fishing mortality to 80% of 1993 levels within two years, primarily by reducing vessel DAS allocations from their initial allocation of 144 DAS to 88 DAS in 1997. Additional seasonal closed areas were added to the coastal areas north of Gloucester. A severe decline in haddock stocks was addressed with a landing limit equal to 300 lbs of haddock per day fished, with a maximum of 3,000 lbs per trip. Enforcement of this limit, like all landing quotas, proved difficult and non-compliance was heavily reported by fisherman and law enforcement alike.

Later that year, the Department of Commerce allocated \$25 million in disaster assistance to purchase and retire fishing vessels. The program received over 160 applications with a total estimated value of over \$58 million. About 80 vessels were purchased and retired, and approximately 22% of the active fishing fleet was removed (Jagodzinski 1997).

In 1996 the U.S. Congress re-authorized the FCMA and implemented the Sustainable Fisheries Act (SFA). This Act required a 10-year rebuilding schedule be enacted for all fish stocks deemed overfished. By 1998, the new requirements of the SFA had not been incorporated into the

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<sup>3</sup> The authors do not indicate if they are referring to "economic collapse," a situation where the fish are so depleted that it is economically unprofitable to continue fishing for them, or "biological collapse," which occurs when the fish are so depleted that the stock is unable to reproduce at a rate sufficient for stock regrowth. I suspect, and the historical record indicates, that they are referring to economic collapse.

groundfish management plan. Gulf of Main codfish stocks were in severe decline, and several emergency actions were implemented by the NEFMC. A series of seasonal closures were implemented off of the New Hampshire and Maine coasts to protect juvenile cod stocks. These closures forced fisherman to either venture farther offshore than they ever had before or relocate to areas that they had not previously fished. The impact of this increased fishing effort in some localities while providing relief for the closed areas. Fisherman were forced to spend more money in either fuel or relocation costs in order to fish, and were therefore under more pressure to increase their catches to compensate (Dobbs 2000).

Stocks of Gulf of Maine codfish continued to decline throughout the late 1990's and complicated landing limits were implemented to regulate cod caught in the Gulf of Maine. At times this limit was as low as 40 lbs of cod per day with a 400 lbs per-trip maximum. A telephone call-in system was set up just for cod fisherman, allowing them to be charged for Days-At-Sea while not actually fishing just so that they could retain their limit of codfish. These regulations proved extraordinarily complicated and nearly impossible to enforce. Furthermore, fisherman reported large amounts of cod being caught and discarded at sea due to the limits, but scientists maintained that the status of this fish stock was getting worse and not better (2000).

Groundfish stocks today are, on the whole, healthier than they were when access to the fishery was limited in 1994 (NEFMC 2001). The haddock landing limits implemented in 1996 have been relaxed, and the biomass of yellowtail flounder is at it's historical high (though much of that biomass resides inside one of the closed areas). Gulf of Maine cod is still in trouble, and the condition of George's Bank cod is declining as well. Both were the subject of a recent court case, again initiated by the Conservation Law Foundation and several other environmental groups, claiming that NMFS has not acted to protect these fish stocks as required by the Sustainable

Fisheries Act. This situation is still evolving, but the initial indications are that fishing effort for all groundfish will see further reductions.

## 1.6 Discussion

In an article titled “Ludwig’s Ratchet and the Collapse of New England Groundfish Stocks” (2000), Tim Hennessey and Mike Healey evaluate groundfish management decisions between 1977-1995 under a hypothesis put forth in a 1993 volume of *Science* by Don Ludwig, Ray Hilborn and Carl Waters (1993). Ludwig, Hilborn and Waters argued that a series of political and economic decisions drives natural resource conservation in a downward spiral. The “ratchet” refers to incentives to invest in resource exploitation during good periods, but strong pressures not to disinvest during poor periods (Ludwig et.al. 1993). Hennessey and Healy go one step further in pointing out that throughout modern groundfish regulatory history, government assistance and incentive to invest has in fact been stepped up during down periods. This can clearly be seen as the number of fishing vessels skyrocketed during the 1980’s.

The fisheries regulations that found favor throughout most of the 1900’s such as minimum mesh size restrictions, species and trip quotas and closed areas raise the cost of capturing fish by decreasing vessel efficiency. For example, increasing mesh sizes forces vessels to fish for a longer period to catch the same amount of fish. Closed areas prohibit fishing in areas where fish may be plentiful, instead forcing fisherman to tow their nets in less desirable areas. There may be a valid biological basis for these types of regulations, but they achieve their conservation goals mainly through the additional costs they impose on fisherman (Iudicello 1998).

Of all the fisheries regulations to have come and gone in New England over the past 50 years, none has had a greater impact on conservation than limited entry and the Days-At-Sea program.

The reductions in time spent fishing and the limitation on the number of fishing vessels allowed to fish are primarily responsible for whatever recovery we are now seeing. Furthermore, they have done so without creating additional inefficiencies in the fishing fleet. It is my contention that, if we are to have any lasting impact on the conservation and rational exploitation of this fishery resource, we must focus our management decisions on the capacity of the groundfishing fleet to capture fish, and the levels of effort with which that capacity is utilized.

## SECTION 2: EFFORT-BASED AND MARKET-ENLISTING FISHERIES MANAGEMENT

### 2.0 Introduction

Concepts of effort-based and market-enlisting management structures are discussed here. As outlined in Section 1, effort limitations are preferable to the other management tools favored by New England groundfish managers because they do not induce vessel inefficiencies and are more likely to be effective at controlling overfishing in most cases. Instead I will concentrate on their applications to fisheries, with particular emphasis on the advantages of effort-based vs. product-based systems.

### 2.1 Limited Entry

The theoretical foundations for limiting entry into the fishery originate with Gordon's *The Economic Theory of a Common-Property Resource: The Fishery*. His simple proposition that a non-exclusive resource capable of generating economic rents would be utilized by an increasing number of people until a point is reached where the rents are entirely dissipated (1954). Very similar to Pigou's traffic congestion model (1932), the concept that increasing numbers of people utilizing a resource reduces the individual benefit derived, and that a point exists where additional resource users negate any individual benefits, was the theoretical basis for limited entry as a fisheries management tool. Limited entry changed New England fisheries management completely, curbing (but not eliminating) the expansion of effort on fisheries resources while granting individual permit owners an inherently valuable right to fish that had not previously existed.

### 2.2 Market-Enlisting Transferable Quotas

Advantages of market-enlisting regimes for use in natural resource management are well known and need not be detailed here. In fisheries management, Francis Christy is widely credited with popularizing market-enlisting management programs to restore resource rents that have been dissipated by overfishing under open-access regimes and/or poor management structures. His ideas found favor with economists and some fishery managers, giving rise to a new fishery management tool now called Individual Transferable Quotas (ITQ's), or Individual Fish Quotas (IFQ's). In essence, an IFQ program divides up the total allowable catch (TAC) from a fishery into percentage "shares" which are distributed to permit holders. These shares translate into a certain amount of fish per year<sup>4</sup>, and they may be bought or sold on an open market. It is important to note that, as stated in the MFCMA, "an individual transferable quota does not constitute a property right" (U.S. Senate 1996).

In the 1980's and 1990's IFQ management systems were implemented in a number of countries, most prominently New Zealand, Iceland and Canada. IFQ's enjoyed a brief popularity with domestic fishery managers as well. Four fisheries in the U.S. were authorized for IFQ management between 1990 and 1995 (National Research Council 1999). On March 21, 1996 the first congressional mandate on ITQ's was signed in to law by President Clinton. The Omnibus Consolidated Rescissions And Appropriations Act Of 1996 stated: "None of the funds appropriated under this act may be used to develop new fishery management plans or amendments which create new individual transferable quota programs, or to implement any such plans or amendments approved by a regional fishery management council or the Secretary of Commerce after January 4, 1995, until offsetting fees to pay for the cost of administering such plans or amendments are expressly authorized under the Magnuson Fishery Conservation and Management Act" (Dept. of Commerce 1996). The 1996 passage of the Sustainable Fisheries

Act (SFA) codified this prohibition<sup>5</sup>. In 2001, Senator Snowe (R-Maine) introduced a bill to amend the MFCMA to “authorize the establishment of individual quota systems” but this bill has yet to leave the Commerce, Science and Transportation Committee (National Journal Group 2001). The MFCMA is currently awaiting reauthorization. No changes in the ITQ moratorium, other than Sen. Snowe’s amendment, are being addressed (United States House Resource Subcommittee 2002).

A second type of quota system, called Individual Effort Quotas (IEQ), faces no such legal challenge. Market-based effort quota systems are similar to their fish quota brethren in that they divide a total amount of resource access into equal shares, which may then be traded. The Sustainable Fisheries Act defines the word “quota” expressly as a unit of fish by weight (US Senate 1996). NEFMC legal advisor Gene Buck has pointed out on several occasions that transferable effort cannot be opposed on legal grounds as a result of the SFA (NEFMC 1996, 1997). This means that while discussions of future domestic IFQ programs are largely theoretical, tradable effort quota’s may be implemented at any time.

### 2.3 Problems Associated With IFQ’s in the New England Groundfish Fishery

Problems associated with quota-based management in New England were highlighted in Section

1. Copes (1986, 1997, 2000) and Jensen and Vestergaard (1999, 2000), among others, have written extensively on problems associated with ITQ management in general. One problem

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<sup>4</sup> The total amount of the shares can vary from year to year, depending on the TAC.

<sup>5</sup> The second incarnation of the MFCMA reauthorization, called the Sustainable Fisheries Act (SFA) and introduced by Sen. Stevens (R-AK) with 8 cosponsors, contained a 4 year prohibition on ITQ’s. The bill was under filibuster for four months by both Senators from Washington State (Slade Gorton, R-Wash., and Patty Murray, D-Wash), who refused to let it pass while it contained any ITQ prohibition (National Journal Group 1996). After the 1996 Appropriations Act passed with the ITQ prohibition, the filibuster lost momentum and the ITQ prohibition was in tact when the SFA was signed into law on October 21, 1996 (U.S. Senate 1996).

specifically associated with market-based fish quota systems in the New England groundfish fishery is highlighted here.

The problem is monitoring and enforcement of a quota system, an ordinarily challenging proposition made nearly impossible by the extreme decentralization of the groundfish fishery in New England. A brief look at groundfish landings in New England illustrates this point. In calendar year 1998, 1,382 individual vessels made 44,945 fishing trips that landed groundfish. These were landed at any one of 497 individual ports on the New England coast (NMFS 1998, NEFSC 2001). Implementing a species quota for each of the 13 groundfish species would mean accurately accounting for all the pounds of each species landed on each of these individual trips—a daunting task.

High rates of fisheries observer coverage have been cited as a potential solution to monitoring problems associated with IFQ programs in multi-species fisheries (Bose et.al. 2000, Copes 1997 among others). The very large number of smaller fishing vessels unable to accommodate full-time fisheries observers, combined with the sheer number of fishing trips that would require coverage makes this a very improbable solution in New England. Dockside monitoring, which is difficult under ideal conditions, would be nearly impossible given the number of offload ports in New England. While regulations could surely be designed to counter some of these difficulties, the costs associated with high rates of observer coverage across this many vessels are likely to be prohibitively high.

#### 2.4 Market-enlisting Effort-based Regimes

There is little literature on IEQ-based management systems. The one example I was able to find comes from the Faroe Islands groundfish fishery, which currently is managed by transferable

effort quotas. Their fishery is multi-species, with 5 species<sup>6</sup> making up the bulk of their landings. In 1994 an IFQ program was instituted. The following is an excerpt from the International Council for the Exploration of the Sea's (ICES) Advisory Committee on Fishery Management, North-western Working Group (2001):

“The catch quota management system introduced in the Faroese fisheries in 1994 was met with considerable criticism and it resulted in at least some fleets misreporting substantial portions of their catches. As a result of the dissatisfaction with the catch quota management system, the Faroese parliament has adopted a law stipulating that the quota system would end as of May 31, 1996. In addition, the Faroese government has developed, in close cooperation with the fishing industry, a new system based on within-fleet category individual transferable effort quotas in days.”

Details on the success of the program can be found in the Report of the North-western Working Group (ICES 2001). Preliminary results are also discussed in Section 7 of this thesis.

In 1996 there was a considerable movement toward a transferable effort program in the Atlantic Sea Scallop fishery. Falling allocations of Days-At-Sea in the fishery (also managed by a DAS program) had forced vessel owners to seek alternative management measures to remain financially solvent. Other changes in this fishery<sup>7</sup> caused the movement to lose momentum, and in December of 1997 the issue was formally rejected by the NEFMC (NEFMC 1997).

## 2.5 Summary and Discussion

It would be possible to write an entire thesis on the issues surrounding market-enlisting quota-based management regimes. I have tried to summarize a few of the most important aspects of these, including the general theory of IFQ's and IEQ's, their current legal status, and their

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<sup>6</sup> Faroe Bank Cod, Faroe Haddock, Faroe Saithe and redfish.

<sup>7</sup> Specifically, the opening of the Closed Areas to limited scalloping mitigated the financial burden of DAS cuts that was driving the move toward transferable fishing effort.

implementation (or lack thereof) world-wide. Market-enlisting programs offer many advantages over other, more traditional fisheries management tools. Quota-based management, however, has a failed history in New England, and the decentralization of the groundfishing fishery does not lend itself well to further experimentation with such systems. There are few effort-based systems world-wide, and it is difficult therefore to draw conclusions about their potential. This, however, should not preclude investigations into their potential utility in the New England Groundfish fishery.

## SECTION 3: FISHING CAPACITY

### 3.0 Introduction

The success of the federal government and local fishing fleets in building more and better fishing vessels during the late 1970's and 1980's created a fishing fleet capable of capturing far more fish than can likely be sustained. The rise in regulatory complexity has led to vast amounts of wasted fishing resources as much of the fishing fleet is utilized either inefficiently or not at all.

Understanding the concepts of theoretical fishing capacity and capacity utilization is therefore critical to assessing the potential for effort-based management.

### 3.1 Capacity and Fishing Capacity

Capacity refers to a firm or organization's ability to generate output when utilized optimally.

Capacity is a maximum likely output (as opposed to an observed or actual output) and is therefore best thought of as a theoretical concept. The U.S. automotive industry, for example, may have the ability to produce 10 million automobiles per year with all manufacturing centers operating all available shifts at full employment. Individual automakers may choose, however, to produce only a fraction of their theoretical maximum output. Capacity utilization is the ratio of observed output to a theoretical maximum production capability (capacity) output. The difference between capacity and actual production may be thought of as excess capacity in the long run (though, for reasons not discussed here, in the short run this is not always the case).

There is no consensus definition of fishing capacity in either the economic or fisheries literature.

Both the Federal Reserve and the U.S. Bureau of Census use a physical definition of capacity called "full production capability," meaning the maximum level of output that a producing unit

could reasonably expect given normal operating conditions. The Bureau of Census further refines this by employing a concept of “sustainable practical capacity,” which is a maximum level of production that a plant could reasonably expect to attain using a realistic employee work schedule, and the machinery and equipment already in place (Bureau of the Census 1997).

Another physical definition was offered by Johansen (1968): “Capacity is the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable factors of production is not restricted.”

Walden and Kirkely (2000) cite three economic (in contrast with physical) definitions which have been “widely used” since their development by C. J. Morrison (1985) and R. Nelson (1989). The first definition sets capacity at the tangent of the short- and long-run average cost curves. The second states “capacity is the output corresponding to the minimum point on the short-run average cost curve,” which implies that capacity should be predicated upon the highest average revenue (minimum average cost). The last holds that “capacity is the output corresponding to the tangency between the long-run average cost curve and the minimum short-run average total cost curve” (this is also referred to as the long-run competitive equilibrium point) (2000).

These definitions may be useful when studying industries with extensive and readily available cost and income data, but because they focus on the cost and not production they fail to capture the true impact of capacity as it relates to the fishery. Furthermore, data necessary for calculating an economic conception of capacity, in particular those of operating costs, are not readily available and may be difficult to model or summarize. For these reasons, most fisheries economists prefer to focus on the physical aspects of capacity as best summarized by the Bureau of Census definition. This was the recommendation of the United Nations Food and Agriculture Organization in their report on fishing capacity (Kirkley and Squires 1999). This is the tack I shall take here.

Like capacity, there is no generally accepted definition for capacity's corollary, over-capacity. The New England Fishery Management Council's Capacity Committee failed miserably when it chose a non-definition for its Final Report on Capacity in the Northeast Multispecies Fishery: "Excess capacity' means that, each year, we "take the available fish" so quickly that society has become dissatisfied" (2000). This definition, in fact this entire line of reasoning, clouds the issue of over-capacity more than it illuminates it.

Judicello, et al. (1999) summarize over-capacity as "an excessive level of catching power; more effort in terms of vessels, time and gear than is necessary to catch the amount of fish available." This definition assimilates the Census Bureau's physical definition, but uses the ambiguous word "available" which would require a normative judgement should this definition be utilized. It is also important to remember that capacity refers to a 'best practice' case, where the inputs (capital and human capital) are utilized at a *maximum reasonable* level. Therefore, a condition of excess capacity does not always result in resource depletion but the opposite is not likely true; in times of resource depletion over-capacity is probably present.<sup>8</sup>

### 3.2 Fishing Capacity and the New England Groundfish Fleet

The only literature detailing capacity levels for the New England groundfish fishery is that of Walden and Kirkley (2000). They chose to focus specifically on otter trawl gear, and therefore their results do not take into account the capacity of either gillnet or hook vessels, both of which are responsible for a significant percentage of total groundfish landings. They utilized a statistical approach called Data Envelopment Analysis (DEA), which essentially traces out a non-parametric "best practice frontier," or maximum daily output, for all vessels analyzed. Their

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<sup>8</sup> Resource depletion clearly linked to causes other than fishing (coastal environmental degradation, for example) would be an obvious exception.

study included all vessels that landed any one of 10 regulated groundfish (red, white, and silver hake were not included because they are captured using a smaller mesh size) or monkfish, which is often caught in conjunction with groundfish. Landing data from 1996-1998 was analyzed, and a maximum daily landing total was computed for each of 484 vessels<sup>9</sup>. This maximum daily landing was multiplied by the Days-at-Sea (DAS) allocation for each vessel to compute a maximum per-vessel annual landing. The results indicated a maximum capacity for this fleet of slightly more than 38,000 metric tons of groundfish, and of 11,500 metric tons of monkfish. Annual landings during the 1996-1998 time period averaged 15,705 metric tons for groundfish (41% of the computed total) and 8,397 metric tons for monkfish (73.2% of computed total capacity). They conclude “given current stock conditions, and the regulatory environment, excess capacity exists in the New England otter trawl fleet” (2000).

By utilizing 1996-1998 data, Walden and Kirkley were attempting to gauge capacity under the most current regulatory environments. Regulatory change can greatly affect a vessel’s ability to capture fish; likewise, changes in resource abundance have a pronounced affect on landings. Interestingly, the regulatory environment present during their research contained at least one significant component that may render their conclusions conservative. Between 1996-1998, haddock, a primary groundfish species, was regulated under a landing restriction that required vessels to land no more than 300 lbs of haddock per day of fishing (with a maximum trip limit of 3,000 lbs) (NEFMC 1998). This restriction was relaxed in the latter half of 1998, first to 1,000 and then 3,000 lbs of haddock per day (with a corresponding 10,000, then 30,000 lbs-per-trip limit). This means that during the timeframe investigated by Walden and Kirkley, vessels were prohibited from landing a large percentage of a species that, after the regulation was relaxed, now comprise a significant percentage of total landings. The haddock landing limit artificially

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<sup>9</sup> NMFS Landing Data indicates that an average of 923 vessels landed more than 300 lbs of regulated groundfish for at least one trip. In 1997, 1092 vessels utilized at least one day at sea (NEFMC 1998). Both

suppressed the maximum daily landing calculations for the vessels analyzed. This regulatory-induced inefficiency is likely to render Walden and Kirkley's conclusions about excess capacity conservative.

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of these figures include gillnet and hook vessels not included in Walden and Kirkley's research.

## **SECTION 4: FISHING EFFORT**

### 4.0 Introduction

This section will describe the concept of fishing effort, especially as it differs from concepts of fishing capacity outlined above. Nominal and actual effort are defined and described, as are the problems associated with latent effort. Understanding these different conceptions of effort is important to understanding both how fishing effort will be modeled in Section 5, and especially to the impacts of the various market structures described in Section 6.

### 4.1 Overview of Fishing Effort

Fishing effort refers to the ability of fishing vessels to translate inputs (vessel and crew) into outputs (pounds of fish, dollars). Effort may also be equated to the impact of those inputs upon the fishery resource. Fishing effort is related to capacity, but the two concepts are not interchangeable. Excess fishing effort is impossible without excess capacity, but the reverse does not hold: excess capacity may exist even while fishing effort is low. A better way to phrase the Iudicello over-capacity definition, therefore, may be: over-capacity is an excessive level of catching power--more *available* effort in terms of vessels, time, etc. The important semantic difference here is that capacity and over-capacity are clearly theoretical concepts--the Census Bureau capacity definition grasps this distinction intuitively. Fishing effort, on the other hand, is a concrete measure.

### 4.2 Nominal Fishing Effort

There are two ways of thinking about fishing effort: either in terms of *nominal effort* or *actual effort*. Nominal effort is the more basic measure. It can best be thought of as a proxy for fishing effort, oversimplified but easily measured. For mobile-gear vessels (otter trawl vessels) it is often equal to time spent fishing. For a trap-based fishery, nominal effort may be equal to the number of traps employed; similarly for the gillnet fishery, nominal effort may be measured as the total number of nets used. For a hook-based fishery (such as those using long-lines or tub trawls), nominal effort may be measured by the number of hooks employed. Nominal effort is a simple but often ineffective substitute for actual fishing effort. It does not take into account the efficiency of time spent operating, nor does it capture differences in production that result from different fishing practices, different targeted species, or different area's fished. In an otter trawl fishery, nominal effort is measured in days. As discussed in Part 1, Amendment 4 to the MFCMA instituted the Days-At-Sea (DAS) program as an effort-control measure for the otter trawl fleet. Therefore, DAS allocated and DAS used are common measures for nominal fishing effort.

#### 4.3 Actual Fishing Effort

Actual effort is the total amount of the fishing fleets' capacity that is directed at a fishery resource. This may be measured instantaneously<sup>10</sup> or over time. It can best be thought of as a measure of the impact that vessels engaged in fishing have upon the fishery resource. The important difference between actual and nominal effort is that actual effort accounts for the fact that vessels of different sizes and gear types will have different impacts upon the fishery resource. Nominal effort treats one effort unit as being equal for all fishing vessels; actual effort, on the other hand, attempts to measure effort's true impact.

Estimating fishing fleet capacity utilization is the most common and widely accepted format for assessing actual effort (Kirkley and Squires 1999). The terms “capacity utilization” and “actual effort” are often used interchangeably for this reason.

#### 4.4 Active Use and Latent Fishing Effort

Nominal fishing effort can be further subdivided into *actual* or *latent use*. Active use, as the name implies, refers to effort that is actively directed at the groundfish fishery. In nominal effort terms, active use refers simply the number of days a vessel spent fishing.

Latent fishing effort refers to fishing effort that is not currently employed, but is available (either actually or hypothetically) for use in the future. The existence of latent effort is one of the largest impediments to fishery recovery because, as expected revenues from fishing increase, latent effort can be converted into actual effort. Latent effort in the New England groundfish fishery is subdivided into three categories: Zero-use, Latent DAS, and History Permits.

Zero-use DAS refers to those DAS that were allocated to vessels at the inception of the DAS program, but have never been utilized. An example of zero-use DAS may be a vessel whose homeport is in North Carolina that fishes primarily for non-groundfish species. As there is very little groundfish found off the North Carolina coast, such a vessel would have to steam to New England to utilize its allocated groundfish DAS. The costs associated with a geographic relocation may not outweigh the expected revenue from fishing for New England groundfish. A vital trait of zero-use DAS, however, is that vessels such as the one in this example may at any time decide to fish for New England groundfish. Such vessels choose whether or not to fish for groundfish based on anticipated market conditions. A slightly different example of zero-use DAS

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<sup>10</sup> F, or the rate of fishery extraction from the fish stock, is a common proxy for fishing effort.

would be the many lobster vessels which do not drag nets but were issued a groundfishing permits (and the corresponding DAS) in 1994. Such vessels may decide that the expected revenues from groundfish fishing minus the costs associated with re-rigging a lobster vessel for groundfish fishing exceed those of lobstering. They are free to utilize their groundfish DAS should they decide that this fishery offers an increase over current revenues, job satisfaction or industry stability (or for any other reasons that fisherman chose to fish).

Latent Days-At-Sea refers to the portion of DAS that were allocated to a vessel that actively fishes for groundfish but were unused during a particular time period. For example, a groundfish fishing vessel may fish only 60 DAS in one year and spend the remainder of the year in a boat yard for maintenance. Assuming this vessel's allocation of DAS is 88 (the industry minimum for a full-time permit), she would have 28 "latent" DAS for that year. The most important aspect of latent DAS is that they, by definition, belong to vessels that are actively engaged in fishing for groundfish. Therefore, the costs associated with geographic relocation or a change in fishing gear type do not apply to these vessels: they are presumed to be ready and able to fish for groundfish with no additional costs.

History permits are those permits (and their corresponding DAS) issued to vessels that are no longer able to fish at all. These vessels are sunk, derelict, or otherwise not available for fishing. Regulations allow for the transfer of such permits to new vessels providing that, among other constraints, the permits are not transferred to vessels that are larger or of greater horsepower than the vessel for which the permit was originally issued. Therefore, history permits are transferable and, should the economic situation warrant fleet expansion, new vessels may be built to utilize them.

#### 4.5 Nominal Effort Allocations

Nominal effort for the New England groundfish fishery is calculated using individual vessel's Days-at-Sea allocations and utilization. In 1994, DAS were allocated to all vessels larger than 5 gross tons. This was expanded in 1996 when DAS were allocated to all vessels permitted for groundfish fishing. The number of permitted vessels allocated DAS increased from 769 in 1995 to 1705 in 1996 due to the expanded scope of the DAS regulations. Likewise, total DAS allocations rose from 140,956 days in 1995 to 236,218 days in 1996. Overall DAS allocations were reduced in 1996 (Amendment 7) to 155,270<sup>11</sup>. As a result of the federal Fleet Buy-Back Program, there were 77 fewer vessels with NEMS permits in 1998 than 1997 (NEFMC 2001, Jargodzinski 1997). A 1998 change in regulations allowed for 10 unused DAS to be carried over into the next fishing year. This change resulted in more DAS allocated in 1998 (156,989) than in 1997. There has been no regulatory change in DAS allocations since that time, and variations in allocation have been minimal (due only to a vessel's ability to carry over the 10 allowable DAS). Preliminary indications for 2001 show fewer DAS were allocated than in either 1999 or 2000 (NEFMC 2001).

#### 4.6 Nominal Effort Utilization

In 1995, 38,527 DAS were used. This number jumped to 51,968 in 1996 as a result of the expanded scope of the DAS regulations. Between 1997 and 1999 DAS utilization remained relatively steady, averaging 51,717 DAS per year. In 2000, however, DAS utilization jumped 9.4 % to 57,078<sup>12</sup> (2001).

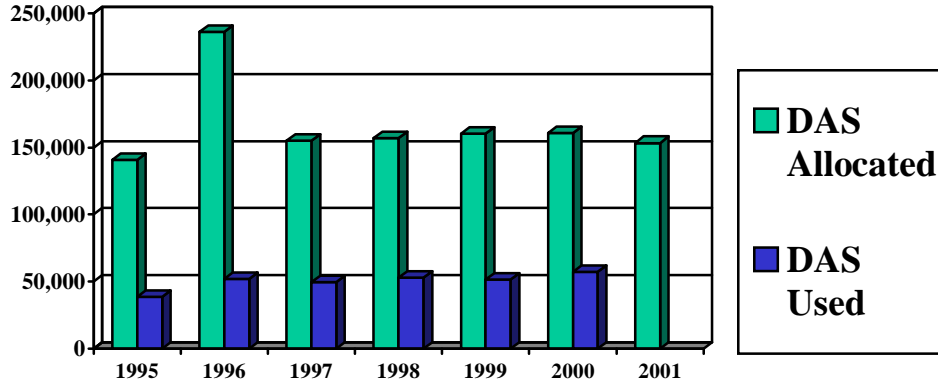
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<sup>11</sup> This was accomplished through a reduction of per-boat DAS allocations. Allocations were reduced to 88 days (average) per boat in 1995 and 51 days (average) per boat in 1996. By 1997, Category B (Fleet) DAS allocations were 88 days, where they have remained through the present (NEFMC 2000).

<sup>12</sup> There are several hypothetical reasons for this change, but no definitive answer has emerged from fishery management experts. One explanation relates to regulations which limit the amount of cod landed in the Gulf of Maine region (north of 42 degrees 20 minutes North latitude). Regulations restrict the number of

Graph 4.1: DAS Allocated and Used, 1995-2001

|                      | 1995    | 1996    | 1997    | 1998    | 1999    | 2000    | 2001    |
|----------------------|---------|---------|---------|---------|---------|---------|---------|
| <b>DAS Allocated</b> | 140,956 | 236,218 | 155,270 | 156,989 | 160,452 | 160,727 | 153,395 |
| <b>DAS Used</b>      | 38,527  | 51,968  | 49,464  | 52,935  | 51,735  | 57,078  | 57,078  |

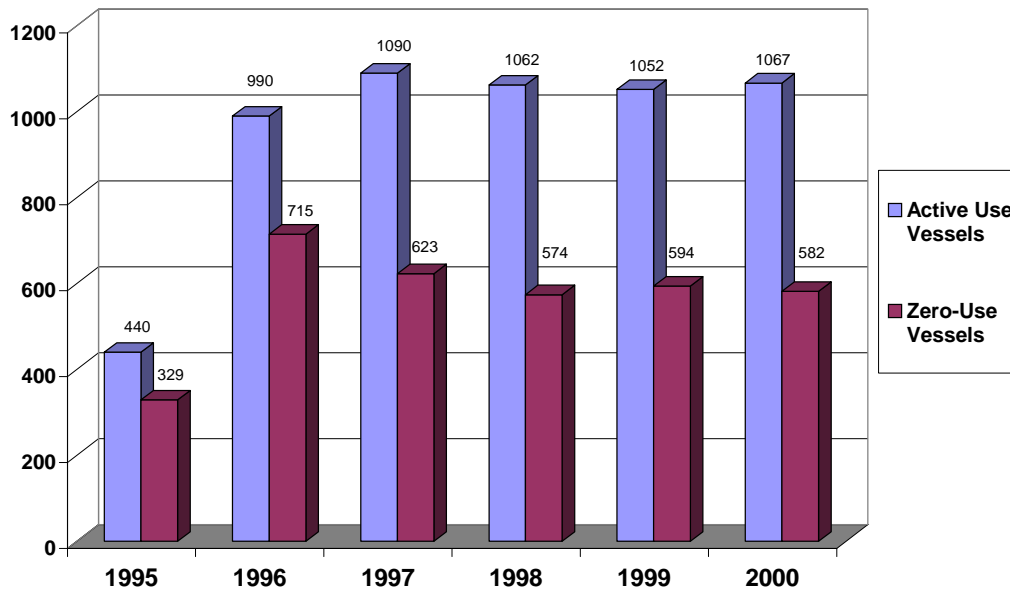


#### 4.7 Latent Fishing Effort: Zero-Use DAS and History Permits

Here we combine the two categories “zero-use DAS” and “history permits.” The level of detail available in the data does not permit delineating between vessels that have fished in other fisheries but not for groundfish, and those vessels that are truly unavailable for fishing in any capacity. Unfortunately, there is no formal record of the number of “history permits” currently in existence. However, we do know that between 1995 and 2000 only 37.5% of vessels allocated DAS used any part of their allocation. This implies that the “zero-use” and “history permit” categories account for 62.5% of all vessels currently allocated DAS.

Graph 4.2: Total Numbers of Active and Zero-Use Groundfish Fishing Vessels

lbs/day fishing vessels are allowed to land in this region. However, these vessels are allowed to “front-load” their DAS clocks by calling in to the DAS program several days prior to departing on a fishing trip. This way, they increase total amount of cod they are able to land, as they were called in to the DAS program for longer than they were actually at sea fishing. Another explanation for the increase is the increasing biomass of haddock and yellowtail flounder (NEFMC 2001). As vessels observe the potential for increased profits, effort that was previously latent may have flowed back in to the fishery.



#### 4.8 Latent Fishing Effort: Latent DAS

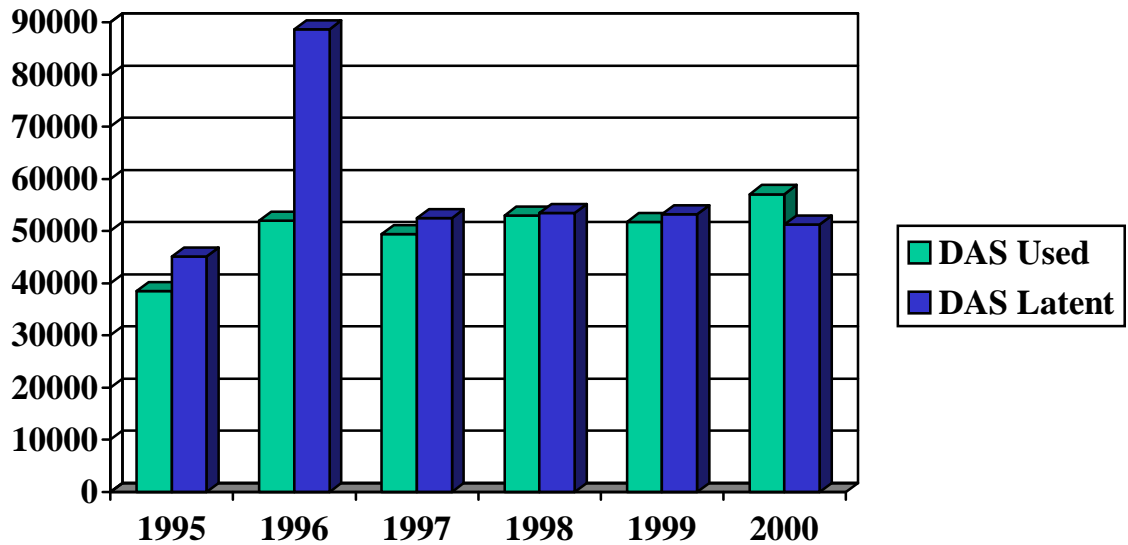
DAS utilization among vessels actively fishing for groundfish has remained relatively constant since 1997. In 2000, however, we saw for the first time that the portion of DAS used by groundfish fishing vessels was greater than that of DAS unused. This may be in response to regulatory changes (particularly the Gulf of Maine cod landing limit<sup>13</sup>), or it may be the beginning of a shift toward greater DAS utilization as vessel owners anticipate greater revenues from the groundfish fishery<sup>14</sup>.

Graph 4.3: DAS Utilization By Year, 1995-2000

|                   | 1995   | 1996   | 1997   | 1998   | 1999   | 2000   |
|-------------------|--------|--------|--------|--------|--------|--------|
| <b>DAS Used</b>   | 38,527 | 51,968 | 49,464 | 52,935 | 51,735 | 57,078 |
| <b>DAS Latent</b> | 45,168 | 88,644 | 52,441 | 53,480 | 53,236 | 51,204 |

<sup>13</sup> The Gulf of Maine cod landing limit regulations imposed a per-day limit for landing codfish north of 42° 20' north latitude. Between 1997 and 2000, this limit has varied from 100 lbs per day to 400 lbs per day. The implication for DAS utilization is that vessels are allowed to begin counting their DAS before actually leaving the dock. If they were to run their DAS clock for 10 days, for example, they can then land 10 days worth of cod regardless of how many days they actually fished on that trip.

<sup>14</sup> Most notably, stocks of George's Bank haddock and George's Bank yellowtail flounder have shown substantial increases. To a lesser extent, winter flounder and GOM cod have as well.



#### 4.9 Summary and Discussion

Fishing effort can be thought of as either nominal or actual. Nominal effort is a simple way of quantifying effort, but it is often incomplete because it fails to capture the effectiveness of effort. Actual effort is a scaled or computed estimation of the impact fishing effort has on the fishery resource. Fishing capacity utilization, the ratio of a vessel's predicted output to its observed output, is the most common quantification of actual fishing effort.

Active use refers to effort actively used. Latent fishing effort refers to units of nominal effort that are not currently employed in the fishery but may, at some future time, be converted into active-use effort units. There are three types of latent effort: latent Days-At-Sea, zero-use DAS and history permits. Of the three forms of latent fishing effort, latent DAS are the most readily available. Vessels with latent DAS are by definition active in the groundfish fishery and there is little or no cost associated with their use. Converting zero-use DAS to active DAS often involves

substantial costs. Re-fitting a lobster vessel for dragging, or replacing herring nets with groundfish nets, can be very expensive, as can relocating a vessel and crew. Zero-use DAS are the least likely to re-enter the fishery. History permits are an available source of fishing effort, should the economics of fishing justify replacing the vessels attached to the permits. DAS belonging to history permits are the least likely to re-enter the fishery due to the high costs associated with vessel acquisition.

Nominal effort utilization in the groundfish fishery averages roughly 35% of the total effort allocated--65% of the available nominal fishing effort has the potential to flow into the fishery. This staggering amount of potential fishing effort, if not addressed, will be converted through investment into active-use effort if and when the economic situation improves. As outlined in Section 1, once investments in the fishery are made at the first sign of favorable conditions, there is little incentive to disinvest once those conditions deteriorate as a consequence of increased effort.

## **SECTION 5: MODELING ACTUAL FISHING EFFORT**

### 5.0 Introduction

Fishing effort modeling is performed to determine actual fishing effort applied to the New England groundfish fishery for any given level of significant inputs. As discussed in Sections 3 and 4, capacity utilization will be used to estimate actual effort levels. Two methods are employed to determine capacity utilization: simple linear regression and the stochastic frontier. These models yield output estimates for otter trawl vessels based on selected fishery inputs. The output estimates derived from the model are then compared to observed output to assess both actual and potential capacity utilization for this fishing fleet. The results are used in Section 6 (Constructing a Fishing Effort Market) to make predictions about future capacity utilization under a tradable effort regime.

### 5.1 Methodology

My objective is to draw upon modeled fishing capacity utilization as a basis for scaling and predicting tradable nominal effort units. Therefore, the model should base inputs solely on physical characteristics of the fishing vessels and not environmental or biological inputs that contribute to fishery output<sup>15</sup>. Model simplicity is an important consideration. As noted in Section 3, there are insufficient data available to pursue economically derived capacity utilization estimates and these will not be addressed here.

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<sup>15</sup> These may include, but are not limited to, changes in stock size or age structure of a particular species, or the changes in different species' relative abundance.

Fishing capacity models relate output to a collection of inputs encompassing significant variables that contribute to the ability of a fishing vessel to produce fish. A generalized per-vessel production model includes the following:

#### Variables

Y output, either in pounds of fish ( $Y_{lbs}$ ) or dollars ( $Y_{\$}$ )

E nominal fishing effort

#### Parameters

A stock abundance

q a vessel's catchability coefficient, which is a function of the vessel's physical characteristics (capital,  $q_K$ ); crew skill (labor,  $q_L$ ); level of technology ( $q_T$ ), and non-discretionary inputs ( $q_{NDX}$ ), where  $q = f(q_K, q_L, q_T, q_{NDX})$

The standard general production function then follows:

$$(5-1) \quad Y = f(q, A, E)$$

A more specific formulation would either be:

$$(5-2) \quad Y_{lbs} = qA E$$

or,

$$(5-3) \quad Y_{\$} = qA E$$

where  $Y_{\$}$  is revenue equal to [ $Y_{lbs} * pp_{\$}$ ] and  $pp_{\$}$  is the average price per pound for the multi-species mix of catch

Rewriting the production function yields an estimate of Catch Per Unit Effort (CPUE):

$$(5-4) \quad Y_{lbs} / E = q A$$

CPUE is typically used to link changes in fishing effort to changes in fishing mortality,  $F$ <sup>16</sup>.

Much of the literature on fishing effort focuses on developing reliable input (effort) based models aimed at anticipating future changes in  $F$ . Other models aim to predict future fishery outputs based on observed inputs.

My modeling objective is different from the goal of many other modeling studies. Instead of predicting future fishery outputs or changes in  $F$ , I hope to establish a baseline catchability relationship among all trawl vessels involved in the groundfish fishery. This approach affords the opportunity to think more directly about the relationship between inputs and outputs in the groundfish fishery.

First, the production function is altered by dropping the “A”(stock abundance) parameter. The underlying assumption here is that all trawl vessels have equal access to fish stocks<sup>17</sup>; the “A” parameter should therefore be constant for all vessels<sup>18</sup>. As stated above, our intention is to scale capacity utilization between vessels based on the “q” parameter, so this decision has the added benefit of practicality. Kirkely and Squires observed that “capacity can be assessed with or

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<sup>16</sup>  $F$  is defined as the rate at which fish are removed from a fish stock. It describes removals due exclusively to fishing, vice other factors such as removal as a result of natural predation or environmental impacts.

<sup>17</sup> A reasonable argument could be made based upon the limited geographic range of the groundfish fishery. On an individual species scale I am not entirely comfortable with this assumption, as many fish stocks reside far offshore beyond the reach of smaller trawlers which are a significant portion of the fishing fleet we hope to regulate. However, I am comfortable with the outcome of this assumption because we have elected to amalgamate all groundfish species.

<sup>18</sup> This hypothesis is tested in Section 4.6.

without the resource stock” (1999). When included, the stock level simply constrains the capacity calculation.

To obtain a per-vessel, per-unit time estimation of capacity utilization, assuming the “A” parameter is dropped, equation (5-4) is rewritten:

$$(5-5) \quad y / e = f(q)$$

Here, estimates of per-vessel, per-unit time capacity utilization are simply an estimation the sum of a vessel’s catchability coefficient (q).

## 5.2 Model Specification

In equation (5-5), observed output, nominal effort, capital, labor and technology form an estimate of capacity utilization. The model I chose is:

$$(5-6) \quad y / e = (q_K + q_L + q_T + q_{NDX})$$

For observed output, I assume that dollars are produced rather than fish. This approach is consistent with Holland (1998, 2000) but different from Kirkely and Walden (2000), who instead chose pounds of fish landed. The idea that fisherman fish for dollars and not fish seems more compelling. A wide range of average ex-vessel prices for different groundfish species, combined with the consequent bias imparted by large volumes of low-dollar product, lends further credence to this approach. Finally, in keeping with our ultimate aim of analyzing market-based DAS transactions, utilizing per-day revenue in our model will yield a more accurate representation of

the value of a DAS<sup>19</sup>. Both Walden and Kirkely (2000) and Kirkley and Squires (1999) point out problems associated with single-point estimates based on multi-product outputs; however, by focusing on relative capacity estimates (i.e. a ratio of one vessel to another) as I will do in Section 5, any bias induced will likely be consistent.

The last term in the production function “ $q_{NDX}$ ” is essentially an error or residual term, “ $\varepsilon$ .”

No data are available on individual vessel’s levels of technology. Based upon personal experience there may be substantial differences in levels of technology among groundfish fishing vessels<sup>20</sup>. Larger vessels (as measured in horsepower, length or gross tonnage) have, on average, a higher level of technology than do smaller vessels. Despite this observation there is no reliable data available and the technology variable “ $q_T$ ” is dropped. I considered using a dummy variable for technology as an option, but this seems ad hoc and would likely produce a greater bias than that created by the omitted variable.

The labor variable “ $q_L$ ” is a measure of crew skill—another variable for which there is no data. It is also dropped, and the impact of crew skill upon output is contained in the error term “ $\varepsilon$ ”<sup>21</sup>. The following production function results:

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<sup>19</sup> Another option would be to convert a complex of multispecies catch, measured in pounds, to dollars based upon an average ex-vessel price.

<sup>20</sup> The author has conducted over 500 law enforcement and safety boardings on over 200 vessels involved in the New England groundfish fishery between 1994 and 1999, affording the opportunity to assess fleet-wide technology levels.

<sup>21</sup> The error term “ $\varepsilon$ ” is assumed to be induced by two sources: neutral, random deviations from the production function (noise) and inefficient--or efficient--input use. Under this assumption,  $\varepsilon = v_i - u_i$ , where  $v_i$  is analogous to the error term in a standard regression model and  $v_i \sim (0, \sigma_v^2)$ . The “ $u_i$ ” term may be thought of as the input of crew skill and is one-sided, distributed half-normal or truncated normal (Lee and Holland 2000, Holland 1998).

$$(5-7) \quad y_s / e = q_K + \varepsilon$$

This is consistent with Kirkely and Squires, who state “it is a short step in this linear, deterministic world to then equate capacity output with the observed capital stock and capacity utilization with capital utilization. When effort is used instead of capital stock, the concepts of available fishing effort and effort utilization are substituted for capital” (1999). This is exactly the approach I have taken here.

### 5.3 Investigating Vessel Characteristic Variables

The final step is investigating the capital variable “ $q_K$ .” There is a substantial literature available regarding estimates of capital levels within individual fisheries (see Ward 2000, Walden and Kirkley 2000, Millischer et. al. 1999, Lee and Holland 2000, Pascoe and Coglán 2000).

Estimations are necessarily constrained by available data (for details on data used in this study, see Appendix D). Walden and Kirkley (2000) and Holland (1998) utilized data sets similar to mine; their work served as a jumping-off point for this portion of the investigation. Holland included four variables for his estimation of “ $q_K$ ”: vessel horsepower (VHP), gross registered tonnage (GTONS), length (LEN), and age (AGE). To these I added number of crew (CREW), yielding:

$$(5-8) \quad y_s / e = f(\text{VHP}, \text{GTONS}, \text{LEN}, \text{AGE}, \text{CREW}) + \varepsilon$$

The data set utilized in this portion of the investigation includes 422 vessels, each of which landed groundfish as a primary species in each year between 1989 and 1993 (see Appendix E for more detail on this data set). Data was available for each of the five variables, and an ordinary

least squares (OLS) regression was used to investigate the significance of the variables. SAS was used to perform the statistical tests.

Initial results from modeling data from several years individually revealed a high level of inconsistency in the CREW variable. Visual inspection of the data exposed extreme variation in the number of crew reported; this variation had little statistical correlation to vessel size or output. For example, several individual fishing trips reported crews numbers of “44,” “55,” and “66.” These were assumed to be data entry errors. As they were both prevalent and extreme, the CREW variable was deemed too unreliable and dropped.

The variable AGE was also subject to great variations in both intercept value and t-statistics from year to year. Vessel AGE refers only to the date the vessel was commissioned (year built). As this variable is intended to measure the affects of capital depreciation, at first blush this seemed sufficient. However, the impact of vessel depreciation is likely to be much higher relative to the age of the vessel’s machinery (i.e. main diesel engine, generators, winches) as opposed to the age of the vessel’s hull. If this is the case, the variability of intercepts and t-statistics observed from AGE is likely due to the fact that the variable is not measuring true capital depreciation. There is no data available on the age of machinery aboard fishing vessels. AGE was dropped from the equation.

LEN, GTONS and VHP remained as the remaining explanatory variables. Slight collinearity was observed between LEN and GTONS. In all versions of the complete model LEN was found to be statistically insignificant at a high level (generally greater than .30). In an effort to keep as many variables as possible, combinations of GTONS and LEN were experimented with (such as  $GTONS * LEN$  and  $GTONS/LEN$ ). These yielded neither a more significant variable nor an increase in goodness-of-fit. It was determined that GTONS was a better estimator for revenue

then LEN, as heavier vessels tend to ride better in a seaway and can therefore fish more efficiently in a greater variety of weather and sea conditions. Some such advantages are afforded to longer vessels as well, but based upon both the significance of the LEN variable and personal experience, I elected to drop LEN.

This yields a final specification:

$$(5-9) \quad y_s / e = f(\text{VHP}, \text{GTONS}) + \varepsilon$$

This specification is tested using two models with two data sets.

#### 5.4 The Ordinary Least Squares Model

The OLS model was used to investigate the significance of input variables. Its estimation of output will essentially yield average production. That is, at the individual vessel level, predicted and actual output may be vastly different, but for the fleet (or data set) predicted and actual output will be nearly identical.

I experimented with several functional forms including log-log and translog. Neither offered an advantage over the non-logged model for either variable significance or goodness-of-fit. This was considered a desirable result, as model simplicity was one of our initial goals (see Appendix F for more details on functional forms). Several relatively minor constraints were placed on the data set. See Appendix G for more details on these.

Results of the OLS model were checked for believability in two ways. First, extreme outlying data was inspected at the individual vessel/trip level. In all cases these outliers were determined,

based on analysis of the landings, to be reasonable, and they remained in the data set. Second, predicted revenue was checked to ensure that it increased as vessel horsepower and gross tonnage increased. This held true for most vessels, though unusual results were observed when horsepower and gross tonnage were at opposite extremes (i.e. very light, high-horsepower vessels and vice versa).

Table 5.1 shows the estimated parameters and t-statistics for the OLS model. Two data sets were utilized. The first includes all otter trawl vessels that landed groundfish at least once in any year between 1989 and 1993. The second includes all otter trawl vessels that landed groundfish at least once in any year between 1995 and 2000.

Table 5.1: OLS Model Parameter estimates and t-statistics

| Variable  | Data Set A<br>parameter | Data Set A<br>t-statistic | Data Set A<br>P >  T | Data Set B<br>parameter | Data Set B<br>t-statistic | Data Set B<br>P >  T |
|-----------|-------------------------|---------------------------|----------------------|-------------------------|---------------------------|----------------------|
| Intercept | 229.83                  | 5.73                      | .0001                | 467.24                  | 9.12                      | .0001                |
| VHP       | 1.61                    | 11.98                     | .0001                | 1.19                    | 7.50                      | .0001                |
| GTONS     | 5.26                    | 10.28                     | .0001                | 11.58                   | 18.78                     | .0001                |

Table 5.2: OLS Model Goodness-of-fit.

|                                       | Data Set A | Data Set B |
|---------------------------------------|------------|------------|
| Goodness-of-fit (adj R <sup>2</sup> ) | 0.615      | 0.538      |

Table 5.3: OLS Predicted and Observed Revenue

|            | OLS Model Fleet Revenue Per Day | Observed Fleet Revenue Per Day |
|------------|---------------------------------|--------------------------------|
| Data Set A | \$ 934,571.20                   | \$ 934,528.60                  |
| Data Set B | \$ 1,801,457.97                 | \$ 1,801,334.24                |

## 5.5 The Stochastic Production Frontier

The Stochastic Production Frontier (SPF) was also calculated for both data sets. SPF is a parametrically derived approach that traces a “best practice frontier” for an industry. Using input variables, the SPF calculates two error terms. The first is a traditional normal error with mean

zero and constant variance, and the second term, which represents technical inefficiency, is expressed as a half-normal or truncated normal distribution (Kirkley and Squires 1999, Kumbhakar 2000)<sup>22</sup>.

In essence, the observed data are individually compared to a calculation of the highest average output obtained by firms (vessels) that utilized identical or highly similar levels of input. Two outcomes result. The first are the parameter estimates, which yield the maximum likely output for each collection of inputs. The second is individual firm efficiency scores (and, consequently, an average fleet efficiency). For the purposes of this investigation, the focus will be on the maximum likely output derived by the SPF model. The efficiency scores are neither directly relevant nor likely to be highly accurate<sup>23</sup>.

Cross-sectional data was employed for the OLS model estimates, but confidence in the accuracy of a production frontier is much higher when panel data is employed (Kumbhakar 2000).

Therefore, each data set was pared down to include only vessels that landed groundfish in each of the years covered.

Table 5.4: SPF Model Parameter estimates and t-statistics

| Variable  | Panel A<br>parameter | Panel A<br>t-statistic | Panel A<br>P >  T | Panel B<br>parameter | Panel B<br>t-statistic | Panel B<br>P >  T |
|-----------|----------------------|------------------------|-------------------|----------------------|------------------------|-------------------|
| Intercept | 711.25               | 143.86                 | .0000             | 689.54               | 10.57                  | .0001             |
| VHP       | 1.61                 | 12.12                  | .0001             | 2.91                 | 13.54                  | .0001             |
| GTONS     | 6.15                 | 10.06                  | .0001             | 11.64                | 15.27                  | .0001             |

Table 5.5: SPF Predicted and Observed Revenue

|         | SPF Model Fleet Revenue Per<br>Day | Observed Fleet Revenue Per<br>Day | Obs/SPF |
|---------|------------------------------------|-----------------------------------|---------|
| Panel A | \$ 824,869.70                      | \$ 614,131.40                     | 0.745   |
| Panel B | \$ 1,256,490.79                    | \$ 860,151.95                     | 0.685   |

<sup>22</sup> The distribution of the technical inefficiency error term may also be an exponential or two-parameter gamma distribution, though the models used here assumed distribution to be half-normal or truncated normal.

## 5.6 Model Consistency Over Time

The final model specification is rather simple—a preferred result, as the model is not intended to either predict future fishery outputs or future rates of fish extraction. Instead, the model is designed to estimate current levels of output using only short-term constant input variables. Furthermore, the modeled output estimates are important only as they relate to one another. Because there exists several exogenous input variables that contribute to future fishery outputs, including “A,” the stock size variable, and the impact of regulatory changes, the parameters generated by these models are not likely to remain accurate predictors of future fishery output. The upward net shift in parameters generated from data in the two time-series’ demonstrates this. These exogenous variables, however, are assumed to affect all vessels evenly due to equal-access to fish stocks, equal impacts of regulation, etc. Because these variables drop out when modeled outputs of different vessels are compared, the difference between multiple vessels’ observed output divided by their modeled output should remain constant over time. I will refer to this difference as the residual ratio<sup>24</sup>,  $\beta$ , where:

$$(5-10) \quad \beta = y_{\text{observed}} / y_{\text{modeled}}$$

For any two vessels  $\beta_X$  and  $\beta_Y$ , the difference between their residual ratios generated by models from the 1989-1993 time-series should be roughly equal to their residual ratios generated by models from the 1995-2001 time-series:

$$(5-11) \quad \beta_{AX} / \beta_{AY} \approx \beta_{BX} / \beta_{BY}$$

where:  $X = 1989-1993$  time-series,  $Y = 1995-2000$  time-series

To check the validity of these assumptions, correlation tests are performed on the OLS and SPF residual ratios of vessels found in both time-series'. The Spearman correlation test is used, as the data are not normally distributed<sup>25</sup>.

The test is applied in two ways. First, the residual ratios for all vessels actively fishing during both the 1989-1993 time-series and the 1995-2000 time-series are compared to check the "equal-access" assumption. The null hypothesis is that the residual ratios of vessels in both data sets are independent. 515 vessels are present in both cross-sectional data sets and 221 vessels are present in both panel data sets<sup>26</sup>.

Fig 5.1: Spearman's correlation test on residual ratios from both data sets

|   |               |
|---|---------------|
| spearman OLS_Residual_A OLS_Residual_B                    |               |
| Number of obs =   | 515           |
| Spearman's rho =  | <b>0.4303</b> |
| Test of Ho: OLS_Residual_A and OLS_Residual_B independent |               |
| Pr >  t  =  | 0.0000        |
| spearman SPF_Res_A SPF_Res_B                              |               |
| Number of obs =   | 221           |
| Spearman's rho =  | <b>0.5050</b> |
| Test of Ho: SPF_Res_A and SPF_Res_B independent           |               |
| Pr >  t  =  | 0.0000        |

Residual ratios from models generated using both time-series' are compared next. Dependent variables (VHP, GTONS) of all vessels from the 1995-2000 time-series are applied to the model parameters generated from the 1989-1993 time-series. The resulting residual ratios are compared

<sup>24</sup> Residual ratio should not be confused with the residual "ε," which is essentially observed output minus modeled output.

<sup>25</sup> There is little practical difference in the results of either the Pearson or Spearman correlation tests, but the Spearman test, which is nonparametric, is generally recommended for non-normally distributed data (Pagano et.al 2000, Anagnoson and DeLeon, 1997).

<sup>26</sup> Residual ratios are compared using STATA

to the ratios generated using the parameters from the 1995-2000 time-series. This verifies the consistency of relative residual ratios over time; in other words, if the parameters computed from current data are applied to future data, we should be able to determine whether the relationship between individual residual ratios is likely to remain constant.

The null hypothesis is that the residual ratios generated from both time-series' models are independent when only vessels from the 1995-2000 are used. There are 1100 vessels present in the cross-sectional data set from this time-series, and 504 vessels present in the panel data set. Residual ratios of the two models are compared.

Fig 5.2: Spearman's correlation test on residuals of models generated from both data sets

|  |               |
|--|---------------|
| spearman OLS_B_re OLS_B_Mod_A                    |               |
| Number of obs =                                  | 1100          |
| Spearman's rho =                                 | <b>0.9786</b> |
| Test of Ho: OLS_B_re and OLS_B_Mod_A independent |               |
| Pr >  t  =                                       | 0.0000        |
| spearman SPF_B_re SPF_B_Mo                       |               |
| Number of obs =                                  | 504           |
| Spearman's rho =                                 | <b>0.9840</b> |
| Test of Ho: SPF_B_re and SPF_B_Mod_A independent |               |
| Pr >  t  =                                       | 0.0000        |

## 5.7 Summary and Discussion

Fishery output, as measured in dollars, changes predictably in proportion to vessel horsepower and vessel gross tonnage. The VHP and GT variables were significant at the 0.01 level with little or no collinearity observed. Other variables investigated such as vessel age, number of crew and vessel length proved to be poor predictors of future revenue. This is likely due to data inaccuracy, in the case of AGE and CREW, and the collinearity extant between LEN and GT.

Two methods of predicting output were investigated: ordinary least squares and the stochastic production frontier. The OLS model yields average daily revenues for individual vessels based upon fleet-wide production levels. The SPF model yields a “best practice” frontier for each vessel based on the maximum observed outputs for each combination of inputs.

A high degree of variability was observed within the data, even among vessels having similar characteristics. While by definition the mean OLS residual ratio was close to one, a large number of vessels produced revenues in excess of three times their predicted output. Several vessels exceeded the SPF, producing more than their “best practice” estimate. Crew skill, random luck and efficient operation are likely to be the primary contributors to these results.

Tests of correlation are not highly robust measures as they do not indicate consistency for each vessel across time periods but rather consistency across time periods for the fleet as a whole.

These methods are adequate for our purposes though, because they demonstrate that the residual ratios of the fleet, regardless of how that fleet is parsed, remain constant over time. The relative difference in residual ratios between two vessels is likely to remain constant despite changes in non-modeled factors such as fish stock size.

The first correlation test compared residual ratios generated by the OLS and SPF models for all vessels fishing in both time-series’ and found that these residual ratios are not independent. The Spearman RHO’s of 0.43 (OLS model) and 0.50 (SPF model) indicate a strong correlation between the residual ratios of both time-series<sup>27</sup>. This result demonstrates that exogenous variables such as stock size and regulatory restrictions affect vessels somewhat, but not perfectly, equally. A correlation approaching 1.0 would indicate zero impact of exogenous variables

(equal-access to fish stocks, equal impact of regulations). A correlation approaching 0.0 would indicate highly differential access to fish stocks and biased regulatory impacts, and the need to incorporate the exogenous variables into the model.

The second test of correlation is a comparison of residual ratios generated by applying parameters of models generated from both time-series' to the vessels included in the data sets of the second time-series. The resulting Spearman's RHO of 0.98 (OLS model) and 0.98 (SPF model) indicate that the residual ratios generated by either model were highly consistent over the two time-series. The almost linear relationship between residual ratios strengthens my confidence that a tradable fishing effort market based upon the residual ratios generated by models from either time-series, and either the OLS or SPF model specification, will remain consistent as fish stock sizes and regulatory environments change.

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<sup>27</sup> A Spearman RHO of 1.0 indicates a perfect linear relationship between the two data sets

## Section 6: Constructing a Fishing Effort Market

### 6.0 Introduction

Section 5 estimates capacity utilization by modeling daily per vessel revenues based on vessel horsepower and gross tonnage. Two methods of modeling output were considered: ordinary least squares (OLS) and stochastic production frontier (SPF). The difference between observed and modeled output (called the residual ratio) was found to be consistent over time for both methods. The methods investigated in Section 5 will now be used to assess potential outcomes of fishing effort trades based on a hypothetical market.

This section has two primary objectives. First, to construct a DAS-based market for fishing effort that scales trades based on the modeled output of each vessel. Scaling trades is necessary because output from one unit of nominal effort (one Day-At-Sea) differs for each vessel. The second objective is to make predictions of fishery changes based upon different buyer/seller permutations. A significant consideration that is investigated thoroughly in this Section is the fact that net fishery output is likely to increase as previously unused DAS enter the fishery, and as DAS shift from less efficient operators to those who are more efficient. Fisheries economics differs from traditional economics on this point, because increases in output are not necessarily desirable<sup>28</sup>. It is essential that DAS trades amongst groundfish fishing vessels not undermine the conservation efforts of fisherman and managers by providing an avenue for unanticipated or uncontrolled increases in actual fishing effort.

### 6.1 Mechanics of Trading

Nominal effort (DAS) trades are predicated on the difference between the modeled output of the two vessels involved in the trade. Specifically, any vessel  $Q$  wishing to purchase “ $e_Q$ ” Days-at-Sea would need to find a seller  $Z$  with “ $e_Z$ ” Days-at-Sea available under the following conditions:

$$(6-1) \quad e_Z = (y_Q / y_Z) * e_Q$$

where:

$y_Q$  = Vessel  $Q$ 's modeled single-day output<sup>29</sup>

$y_Z$  = Vessel  $Z$ 's modeled single-day output

$e_Q$  = Vessel  $Q$ 's DAS purchased

$e_Z$  = Vessel  $Z$ 's DAS sold

In practice, this is a simple calculation. Take a hypothetical case where the owners of F/V PATTI desire to increase their nominal effort allocation from 88 DAS to 120 DAS. F/V PATTI's modeled single-day output is \$1,500. The owners of another vessel, F/V CAROLINE, which has a single-day modeled output of \$2,000, desire to sell a portion of their 88-day DAS allocation. To calculate the number of DAS F/V PATTI may purchase from F/V CAROLINE we use equation (6-1). Assuming 32 DAS are desired by F/V PATTI, the following calculation results:

$$d_{\text{CAROLINE}} = (1500/2000) * 32 = 24$$

Hence, F/V PATTI purchases 32 DAS from F/V CAROLINE, who loses 24 DAS. This sale has a neutral impact on modeled fishery output—according to the model, it takes 32 days for F/V PATTI to generate the same level of output that F/V CAROLINE generates in 24 days. This ensures that the modeled output of the fishery as a whole does not increase with DAS trades.

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<sup>28</sup> Nor, depending on initial output levels, are they likely to be sustainable.

<sup>29</sup> All values in this section for “ $y$ ” or “ $Y$ ” are assumed to be in dollars.

## 6.2 Selecting a Model For Output

Four versions of modeled output were outlined in Section 4:

1989-1993 Time-Series, OLS Model

1995-2000 Time Series, OLS Model

1989-1993 Time-Series, SPF Model

1995-2000 Time-Series, SPF Model

The predominant difference between the two time-series' is that predicted outputs from 1989-1993 are likely to be more indicative of potential vessel capacity utilization in that they are less constrained by the regulatory environment than those of the 1995-2000 time-series<sup>30</sup>. Several regulations, most prominently the year-round closed areas and cod and haddock landing limits, severely constrained actual output during the latter time-series. However, models based on the 1995-2000 data may be more appropriate for assessments of future outputs. There were significant changes in the composition of the groundfish fleet between the two time-series. The variables horsepower and gross tonnage do not stabilize until 1994 when limits on upgrading vessels were imposed. More vessels, and hence more data points, are included in the 1995-2000 time-series. For these reasons, I use the 1995-2000 time-series as the basis for analyzing potential trades.

A comparison between hypothetical markets based on SPF and OLS estimations of output revealed very little difference in trade predictions or anticipated total fishery output (see Appendix I for details on this comparison). However, I contend that SPF modeled output provides a significant improvement over OLS modeled output that is not captured in the

hypothetical markets. The “best practice” frontier aspect of the SPF model provides an in-built incentive for vessels that have historically operated farther from their estimated frontier to sell their DAS allocation. With the SPF method, the expected market value of a DAS for a typically under-performing vessel is relatively greater than it would be if trades were scaled on an OLS average predicted output. The reverse is also true: the market value of a DAS is less for those vessels operating at or near their maximum likely frontier, relative to what they would expect to see if trades were scaled on OLS-based output estimates. Hence, the incentive for shifting DAS from less efficient to more efficient vessels is higher under a trading system based on output estimates from the SPF vice those of the OLS method, though the sample markets created here cannot capture this incentive.

Furthermore, the SPF has a conservation advantage over OLS-based output estimates. The “best practice” frontier nature of the SPF ensures that the difference between observed and modeled output (the residual ratio) is smaller than a similar ratio for OLS-based output estimates. This means that the difference between modeled and actual output is much less using SPF estimates. The changes in total fishery output, therefore, are less extreme when trades are based on SPF output estimates rather than OLS output estimates. While this theory is not tested here, it appears logical that unanticipated increases in actual effort are less likely under a market based on SPF-derived modeled outputs.

Consequently, the SPF model generated from panel data in the 1995-2000 time-series is used as the basis for modeled output. The parameters from the SPF model are applied to the cross-sectional data from the 1995-2000 time-series. This data set is amended slightly from that used for OLS estimations in Section 4. Appendix J contains details on this final data set.

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<sup>30</sup> See Appendix E for more details regarding the data sets

### 6.3 Overview of Trade Prediction

Equation (6-1) can be rewritten in per-vessel terms by dropping either vessel. The result is a net annual allocation of quality-adjusted<sup>31</sup> DAS for each vessel. The concept of a quality-adjusted DAS is explained mathematically:

$$(6-2) \quad \alpha_i = e_i * y_i$$

where:

$\alpha_i$  = total quality-adjusted DAS per-vessel

$e_i$  = number of DAS to be bought or sold

$y_i$  = vessel  $i$ 's modeled single-day output

Net quality-adjusted DAS can be calculated for all vessels predicted to be buyers and all vessels predicted to be sellers<sup>32</sup>. The point where there is no net excess demand for or supply of quality-adjusted DAS can be expressed:

$$(6-3) \quad \sum_i (\alpha_{i\text{BUYER}}) = \sum_i (\alpha_{i\text{SELLER}})$$

At this point the market is assumed to clear and no further DAS trades are anticipated.

### 6.4 Predicting Changes in Net Fishery Output With DAS Trades

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<sup>31</sup> This quality-adjustment is simply factoring each DAS by its anticipated (modeled) output.

<sup>32</sup> Buyer/seller criteria are discussed in Section 6.5.

Predictions of changes in net fishery output are made with a few simple calculations. First, the DAS allocations for vessels predicted to be buyers are multiplied by their per-day output; these are summed. This number is added to the sum of all the observed annualized outputs for vessels that are neither buyers nor sellers. The result is an estimation of total annualized fishery output after anticipated DAS trades. This number is divided by the sum of observed annualized outputs from all vessels in the data set prior to trading, yielding an anticipated percentage increase in annual fishery output. This is summarized as follows:

$$(6-4) \quad \% \Delta Y = \frac{\sum_i (y_i^* * e^*)}{\sum_i (y_i * e)}$$

where:

$y^*$  = predicted annual vessel output after DAS trades

$y$  = observed annual vessel output prior to DAS trades

$e^*$  = predicted annual vessel DAS allocation after DAS trades

$e$  = observed annual vessel DAS usage

These predictions assume constant output--percentage increases are predicted based upon current output models. This constant output assumption is likely to bias the estimates, as output will not remain constant as fishery resources are expended (a consequence of increased fishery output). If output exceeds the carrying capacity of a fish stock, catch-per-unit-effort will decline and estimates of output from models based on prior data will exceed actual outputs (Hannesson 1974, Iudicello 1999). Estimates of net fishery output increases are therefore likely to be inflated.

## 6.5 Defining Buyers and Sellers

I use three indicators to make buyer and seller predictions: historical DAS utilization, residual ratios, and equilibrium market-clearing price. In this simplified market, buyers are assumed to want to buy the maximum available quota and sellers are assumed to sell their entire allocation. It is necessary to create an artificial cap for DAS allocations, which must fall somewhere between the current allocation of 88 DAS per year and the maximum potential allocation of 365 DAS per year. I chose a cap of 180 DAS per year. This represents roughly the number of days fished per year by the 100 most active fishing vessels between 1989-1995<sup>33</sup>.

All vessels predicted to buyers are assumed to utilize their entire newly-acquired DAS allocation. The bias associated with this assumption, especially when combined with the constant-output assumption outlined in Section 6.5, will likely yield output estimations that are higher than they would be under real-world circumstances.

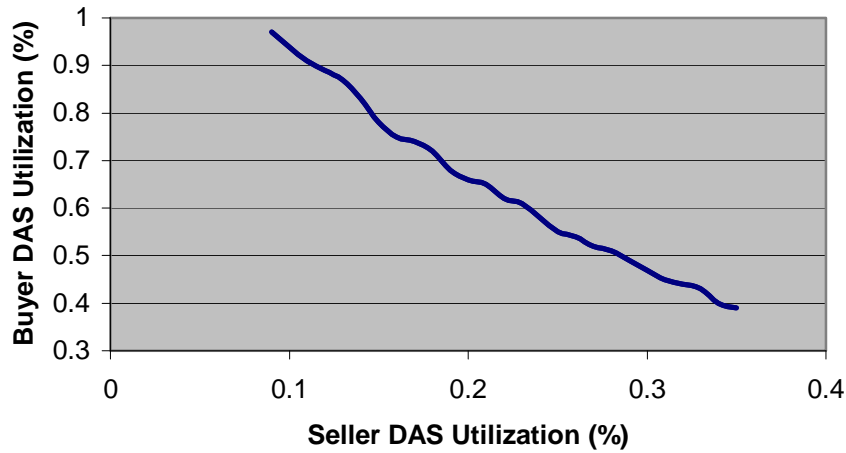
## 6.6 Predicting Trades Based On Historical DAS Utilization

The assumption underlying this criterion is that vessels which have historically utilized a low percentage of their DAS allocations are more likely to be sellers, and those utilizing the bulk of their allocations are likely to be buyers. Equation (6-3) is used to determine utilization rates necessary for both buyers and sellers to clear the market. An isoquant represents combinations of buyer DAS utilization rates and seller DAS utilization rates, such that the total amount of quality-adjusted DAS allocated to buyers is equal to that allocated to sellers.

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<sup>33</sup> See Section 7 for discussion of this cap.

Fig 6.1: Corresponding DAS utilization rates for sellers and buyers at market equilibrium



At any point on this line it is possible to predict how many, and even which, vessels are likely to be buyers and sellers. Equation (6-4) enables predictions of changes in net fishery output resulting from these trades. The following table summarizes selected results from this market. See Appendix K for more detailed results.

**TABLE 6.1: SUMMARY OF TRADES AT VARIOUS DAS UTILIZATION RATES**

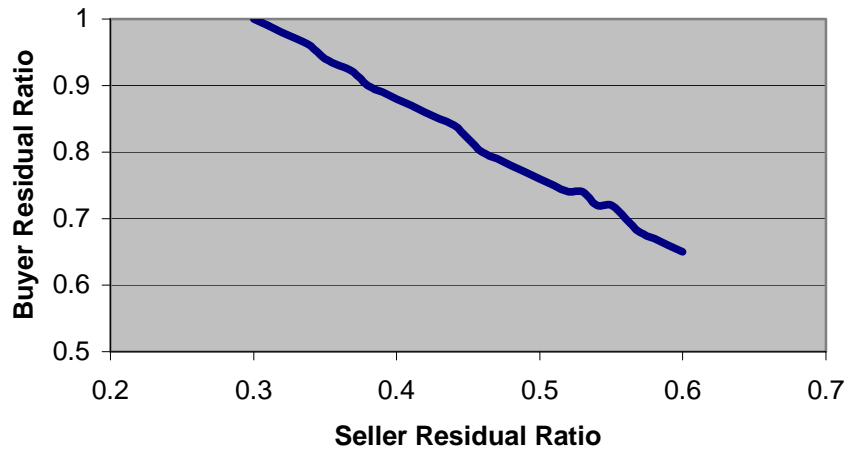
| Seller DAS Utilization (%) | Buyer DAS Utilization (%) | Buyer DAS |          | Mean                      |                               | Predicted Increase in Total Fishery Output | Change in Net DAS Allocated |
|----------------------------|---------------------------|-----------|----------|---------------------------|-------------------------------|--|-----------------------------|
|                            |                           | # Sellers | # Buyers | Residual Ratio of Sellers | Mean Residual Ratio of Buyers |  |                             |
| 0.35                       | 0.39                      | 423       | 426      | 0.55394                   | 0.73105                       | 83.52%                                     | -4.44%                      |
| 0.30                       | 0.47                      | 368       | 374      | 0.53804                   | 0.73388                       | 70.94%                                     | -3.96%                      |
| 0.25                       | 0.55                      | 326       | 323      | 0.52562                   | 0.73587                       | 59.50%                                     | -4.98%                      |
| 0.20                       | 0.66                      | 263       | 263      | 0.51353                   | 0.75185                       | 48.60%                                     | -4.76%                      |
| 0.15                       | 0.78                      | 188       | 188      | 0.51662                   | 0.76664                       | 33.45%                                     | -3.97%                      |
| 0.10                       | 0.94                      | 95        | 99       | 0.48339                   | 0.80975                       | 16.19%                                     | -2.09%                      |

### 6.7 Predicting Trades Based On Residual Ratios

The assumption underlying this criterion is that vessels which operate farther from their SPF modeled revenue are more likely to be sellers, and those operating at or close to their maximum frontier are likely to be buyers. Equation (6-3) is used to determine utilization rates necessary for

both buyers and sellers to clear the market. An isoquant represents combinations of buyer residual ratios and seller residual ratios, such that the total amount of quality-adjusted DAS allocated to buyers is equal to that allocated to sellers.

Fig 6.2: Corresponding residual ratios for sellers and buyers at market equilibrium



Similar to the DAS utilization method, it is possible to predict how many, and which, vessels are likely to be buyers and sellers at any point on this line. Predictions of changes in net fishery output resulting from these trades are made. The following table summarizes selected results from this market. See Appendix L for more detailed results.

**TABLE 6.2: SUMMARY OF TRADES AT DIFFERENT RESIDUAL RATIOS**

| Residual Ratio-Seller (<) | Residual Ratio- Buyer (>) | # Sellers | # Buyers | Mean Residual Ratio-Sellers | Mean Residual Ratio-Buyers | Anticipated Increase in Fishery Total Output | Change in Net DAS Allocated |
|---------------------------|---------------------------|-----------|----------|-----------------------------|----------------------------|--|-----------------------------|
| 0.60                      | 0.65                      | 424       | 410      | 0.40240                     | 0.90448                    | 115.89%                                      | -53.45%                     |
| 0.55                      | 0.72                      | 360       | 333      | 0.37195                     | 0.95565                    | 102.40%                                      | -45.04%                     |
| 0.50                      | 0.76                      | 301       | 283      | 0.34207                     | 0.99345                    | 90.31%                                       | -37.65%                     |
| 0.45                      | 0.82                      | 246       | 230      | 0.31381                     | 1.04045                    | 78.22%                                       | -30.64%                     |
| 0.40                      | 0.88                      | 194       | 182      | 0.28394                     | 1.09050                    | 63.35%                                       | -24.02%                     |
| 0.35                      | 0.94                      | 140       | 134      | 0.24895                     | 1.15570                    | 49.60%                                       | -16.95%                     |
| 0.30                      | 1.00                      | 99        | 93       | 0.21583                     | 1.23733                    | 36.40%                                       | -11.93%                     |

### 6.8 Predicting Trades Based On Equilibrium Market-Clearing Price

To determine an accurate market-clearing price, reliable data on vessel costs are required. The National Marine Fisheries Service provides a parametric approximation of daily operating costs<sup>34</sup>. This approximation does not take into account annual or long-term operating costs, and therefore the estimations that follow are more valuable as a reference point than as actual representations of true profitability.

The following profitability formula is utilized:

$$(6-5) \quad \text{profit}_i = [ y_i - k_i - (\alpha_i * p) ] / e_i$$

where:

$y_i = ( x_i + \varepsilon_i )$  = total observed revenue per vessel where  $x_i$  is the modeled single-day output and  $\varepsilon_i$  is the residual

$k_i$  = total cost of operation per vessel

$\alpha_i = [ d_i * x_i ]$  = total quality-adjusted DAS

$p$  = price per unit of additional quality-adjusted DAS

$e_i$  = total DAS to be bought or sold

Rewriting equation (6-5) in a per-day form yields Profit Per Day (PPD):

$$(6-6) \quad \text{PPD}_i = y_i - k_i - (\alpha_i * p / e_i)$$

Substituting for  $y_i$  and  $\alpha_i$ :

$$\begin{aligned}
 (6-7) \quad \text{PPD}_i &= (x_i + \varepsilon_i) - k_i - (x_i * p) \\
 &= x_i (1-p) + \varepsilon_i - k_i
 \end{aligned}$$

The pool of available quality-adjusted DAS for sellers and buyers can now be analyzed to predict which vessels are likely to trade. For this market, buyers are predicted to be any vessel with a positive PPD, and sellers are predicted to be any vessel with a negative PPD at the calculated market clearing price.

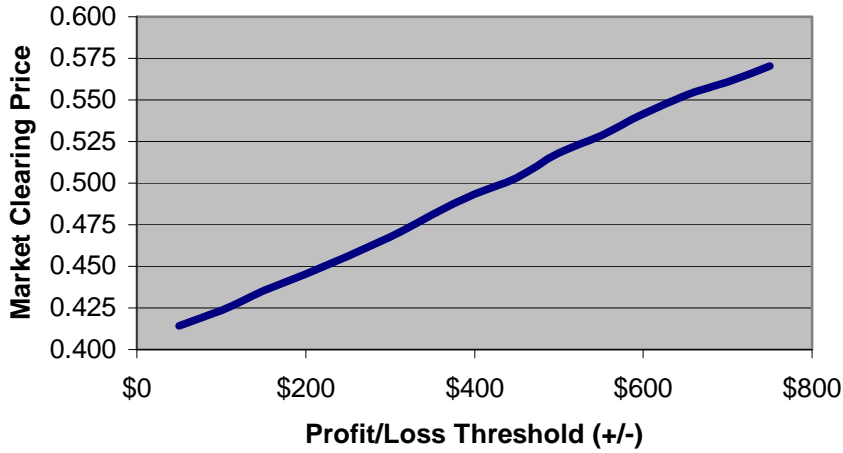
Equations (6-3) and (6-7) can be used to calculate the market-clearing price (MCP) precisely. The price for a quality-adjusted DAS stabilizes at the point of no net excess demand for or supply of quality-adjusted DAS. Using equations (6-3) and (6-7) and available cost data, the market-clearing price for a quality-adjusted DAS is calculated to be **\$0.4053**.

This market can be adjusted to account for vessels operating at or near their predicted profitability based upon the MCP by including a profit/loss threshold defining buyers and sellers. This yields an isoquant representing combinations of profit/loss threshold and MCP, such that the total amount of quality-adjusted DAS allocated to buyers is equal to that allocated to sellers.

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<sup>34</sup> The daily operating cost formula for otter trawl vessels in New England [196.03 – 1.998\*GTONS + 1.23\*VHP] was provided by the Social Sciences Branch of the Northeast Fisheries Science Center.

Fig 6.3: Corresponding profit/loss threshold and MCP for sellers and buyers at market equilibrium



Trade predictions and anticipated changes in total fishery output and net DAS allocated are made. The following table summarizes potential trades based the MCP criteria at various profit/loss thresholds.

**TABLE 6.3: SUMMARY OF TRADES PREDICTED BY THE MCP AT VARIOUS PROFIT/LOSS THRESHOLDS**

| Profit/Loss Threshold | MCP      | Avg. Price Paid per DAS | # Sellers | # Buyers | Mean Residual Ratio-Sellers | Mean Residual Ratio-Buyers | Anticipated Increase in Fishery Total Output | Change in Net DAS Allocated |
|-----------------------|----------|-------------------------|-----------|----------|-----------------------------|----------------------------|--|-----------------------------|
| \$50                  | \$0.4143 | \$1,172.88              | 462       | 418      | 0.42290                     | 0.89406                    | 118.58%                                      | -11.81%                     |
| \$150                 | \$0.4355 | \$1,237.79              | 437       | 399      | 0.41089                     | 0.90549                    | 111.92%                                      | -15.82%                     |
| \$250                 | \$0.4561 | \$1,300.11              | 409       | 374      | 0.39724                     | 0.92020                    | 102.29%                                      | -21.09%                     |
| \$350                 | \$0.4810 | \$1,371.02              | 375       | 351      | 0.38157                     | 0.93611                    | 93.12%                                       | -25.95%                     |
| \$450                 | \$0.5029 | \$1,438.86              | 339       | 324      | 0.36826                     | 0.95486                    | 82.20%                                       | -31.64%                     |
| \$550                 | \$0.5285 | \$1,518.57              | 307       | 302      | 0.35452                     | 0.97024                    | 73.09%                                       | -36.28%                     |
| \$650                 | \$0.5526 | \$1,580.81              | 282       | 282      | 0.34515                     | 0.98547                    | 63.46%                                       | -40.50%                     |
| \$750                 | \$0.5702 | \$1,620.59              | 252       | 263      | 0.33572                     | 1.00269                    | 54.17%                                       | -44.51%                     |

It is important to note that the price paid per vessel to purchase a DAS differs dramatically according to the vessel’s modeled output. To calculate the price paid per DAS ( $d_s$ ) for an individual vessel, multiply the MCP by equation (6-2):

$$(6-8) \quad d_s = \text{MCP} * \alpha_i$$

$$= \text{MCP} * e_i * y_l$$

At the MCP with no profit/loss threshold, all vessels in the data set are predicted to be either buyers or sellers. One result of this is a very large total amount of quality-adjusted DAS ( $\alpha$ ) traded. In all permutations of the three markets, predicted fishery output rose in direct proportion to the size of “ $\alpha$ .”

See Appendix M for more detailed results. Appendices N, O and P also look more closely at different permutations of the MCP approach.

## 6.9 Summary and Discussion

A market for DAS is created by scaling DAS trades on stochastic production frontier estimates of per-vessel output. The choice of the SPF as the basis for modeled output provides additional, though not captured, incentives for DAS to shift from inefficient to efficient vessels and minimizes the impact of unanticipated increases in actual fishing effort as a result of this market. Trades are predicted by calculating a market-clearing point, where the quantity of quality-adjusted DAS demanded is equal to that supplied. Three criteria for defining buyers and sellers are investigated: historical DAS utilization, vessel residual ratios, and a calculated market-clearing price for quality-adjusted DAS. The results of sample market trades demonstrate that, regardless of how buyers and sellers are predicted, net output from the fishery will increase substantially. This increase is due to two factors: the shift in DAS from inefficient to efficient operators, and the predicted increase in DAS utilization of the fleet as a whole.

TESTING THE “EFFICIENCY SHIFT”

The impact of DAS shifting towards efficient operators is investigated by creating a market that includes only vessels with very high historical DAS utilization. For this market, all vessels with historical DAS utilization rates less than 88% are excluded, leaving 121 vessels in the data set.

The following table summarized anticipated trades and predicted increase in total fishery output.

Table 6.4: Summary of MCP-based trades by vessels with historical DAS utilization > 0.88

| MCP   | # Sellers | # Buyers | Mean Residual Ratio of Sellers | Mean Residual Ratio of Buyers | Predicted Increase in Total Fishery Output (%) | Change in Net DAS Allocated (%) |
|-------|-----------|----------|--------------------------------|-------------------------------|--|---------------------------------|
| 0.514 | 49        | 72       | 0.52732                        | 0.97281                       | 14.30%   | 0.31%                           |

It is important to note that the characteristics and potential outputs of vessels included in this restricted market differ significantly from those of the fleet as a whole. The following tables summarize these differences.

Table 6.5: Comparison of vessel characteristics between market data set and a sub-set of this market restricted to vessels with historical DAS utilization > 0.88

|                     | # vessels | Mean VHP | Mean GT | Mean Daily Output |
|---------------------|-----------|----------|---------|-------------------|
| Complete Data Set   | 902       | 203.42   | 55.2    | 1641.6            |
| Restricted Data Set | 121       | 462.31   | 82.0    | 2386.15           |

Table 6.6: Comparison of residual ratios for buyer and sellers between market data set and a sub-set of this market restricted to vessels with historical DAS utilization > 0.88

|                     | Mean Residual Ratio of Sellers | Mean Residual Ratio of Buyers |
|---------------------|--------------------------------|-------------------------------|
| Complete Data Set   | 0.42290                        | 0.89406                       |
| Restricted Data Set | 0.52732                        | 0.97281                       |

While vessel horsepower, gross tonnage and output are on average much higher for the restricted market, the differential between buyer/seller residual ratios for the unrestricted and restricted markets is within 10%. We can therefore make very general comparisons between the unrestricted market and it's restricted counterpart based on the elimination of latent DAS. The relatively low net change in total output for the restricted market (14.3%) lends credence to the

conclusion that increases in output due to changes in fleet efficiency are significant, but not as significant as increases due to the overall DAS utilization of the fleet.

Appendix N includes an attempt to gauge the magnitude of the percentage change in output due to changes in fleet efficiency.

#### THE FLEET-WIDE INCREASE IN DAS UTILIZATION

In all markets, DAS utilization is assumed to be 100% for buyers. This assumption translates to dramatic increases in DAS utilization, even while overall DAS allocations are reduced through trading. Preliminary evidence suggests that the increase in DAS utilization is responsible for a greater proportion of the overall increase in output than changes in fleet efficiency. To test the impact of the fleet-wide increase in DAS utilization, markets are constructed to exclude historically unused DAS. Vessels predicted to be sellers based on the DAS utilization, residual ratio and MCP criteria are assumed to sell a total number of DAS equal to their average DAS use from 1995-2000. Buyers are still assumed to use their DAS at a 100% rate, but with all latent DAS removed from the market valid comparisons between these sample markets and those including latent DAS should allow us to draw preliminary conclusions as to the impact of increasing fleet-wide DAS utilization rates.

The following table summarizes anticipated trades based on markets where latent DAS have been eliminated. For the change in net DAS allocated column in this table, allocations are assumed to be active-use DAS only. For the MCP criteria, the profit/loss threshold is set at zero.

**TABLE 6.7: SUMMARY OF TRADES EXCLUDING LATENT DAS**

| Method                 | Market Clearing Equilibrium | Avg. Price Paid per DAS | # Sellers | # Buyers | Mean Residual Ratio of Sellers | Mean Residual Ratio of Buyers | Predicted Increase in Total Fishery Output (%) | Change in Net DAS Allocated (%) |
|------------------------|-----------------------------|-------------------------|-----------|----------|--------------------------------|-------------------------------|--|---------------------------------|
| <b>DAS Utilization</b> | 0.28/1.00                   | N/A                     | 251       | 66       | 0.52959                        | 0.78010                       | 3.03%  | -31.20%                         |
| <b>Residual Ratio</b>  | 0.45/1.12                   | N/A                     | 246       | 54       | 0.31381                        | 1.37424                       | 18.20%   | -23.70%                         |
| <b>MCP</b>             | 0.6069                      | \$1,706                 | 676       | 226      | 0.51695                        | 1.03647                       | 36.00%   | -13.00%                         |

The predicted increase in total fishery output is between 50% and 75% less than the increase predicted by the markets when latent DAS are included. This provides further evidence that the introduction of previously latent DAS accounts for a far larger increase in total fishery output than does the change in fleet-wide efficiency.

## Section 7: Policy Implications

### 7.0 Introduction

As discussed in Sections 1 and 2, management of the New England groundfish fishery has become a complex and often confusing web of controls that regulate the fishery, in large part, by making vessels and fisherman inefficient. Government-induced incentives for investment in the fishery have led to fleet over-capitalization. Initial allocations of Days-At-Sea<sup>35</sup> were ad-hoc, and subsequent DAS reductions have left year-round groundfishing vessels with limited time to ply their trade<sup>36</sup>. DAS allocations have also created a vast source of fishing effort that can flow into the fishery at the first sign of industry recovery. These have combined to create a fleet that possesses, should all permitted vessels commence fishing, fishing capacity vastly in excess of the carrying capacity of the resource. Many, if not most, of the complicated fishery regulations currently in use have been enacted to deal with affects of this over-capacity. A period of resource decline has followed, as too many vessels compete for too few fish.

As highlighted in Sections 1-4, two significant problems have arisen in the groundfish fishery. First, fishery regulations have grown increasingly complex, resulting in decreasing efficiencies for all fishing vessels and reduced access to groundfish stocks for those vessels able to operate relatively efficiently. The second is the creation of a large amount of latent effort, which may re-enter the fishery at any time. The objective of a market for fishing effort is therefore twofold: to allow for the efficient distribution of nominal fishing effort (Days-At-Sea) among vessels, and to provide fishery regulators with a tool to control the flow of latent effort into the fishery. The ability to trade DAS amongst groundfishing vessels would enhance the efficiency of the

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<sup>35</sup> See Section 1 and 4 for details on initial DAS allocations.

groundfish fleet. Allowing individuals who no longer wish to fish the opportunity to receive compensation for leaving the fishery, and allowing individuals with a desire to fish more than their current DAS allocation the ability to do so, would offer policy makers a valuable tool for addressing issues of excessive latent effort. This section addresses policy issues arising when assessing the ability of a market-enlisting effort quota regime to address these two problems.

### 7.1 Monitoring and Enforcement

Section 2 makes reference to the difficulties surrounding monitoring and enforcement of species quota based management systems. Effort-based systems are offered as a superior choice for the groundfish fishery in New England. One reason not yet addressed is the ease of monitoring and enforcement for such a system.

Effort-based management became a significant part of the groundfish fishery with the inception of the Days-At-Sea program in 1994. Under the program, vessels have two options for using reporting their use of fishing days. The first is a telephone call-in/call-out system where the vessel operator places one call prior to leaving the dock on a groundfish fishing trip and another upon returning. At each call he or she is given a 14-digit number, called their “sailing” and “landing” numbers. The first two digits of their number signify the month, the next two the day, and the next four the hour and minute of their call. The last six numbers are sequential reference numbers. An example DAS number may be 03010532196427, broken down as follows:

Fig 7.1: Example DAS number

| Vessel Name | Permit Number | Month | Day | Hours | Minutes | Reference Number |
|-------------|---------------|-------|-----|-------|---------|------------------|
| F/V HAROLD  | 152362        | 03    | 01  | 05    | 32      | 196427           |

<sup>36</sup> In 2001, 1,128 vessels were authorized 88 DAS (called “fleet DAS”) and 136 vessels were authorized DAS based upon their historical utilization (called “individual DAS”). The average allocation for the

The other option available to users of this program is called the Vessel Monitoring System (VMS). The VMS program uses a commercially available Global Positioning System (GPS) based unit that monitors a vessel's location at all times. When a vessel crosses a pre-determined demarcation line, NMFS is automatically notified via the VMS unit, and the vessel begins utilizing their allotted DAS.

Enforcement of both programs is straightforward, especially in comparison to enforcement of other fisheries regulations. For the call-in/call-out system, NMFS and U.S. Coast Guard enforcement units are provided daily updates of vessel receiving "sailing" and "landing" numbers. If a vessel not listed as called-in to the program is sighted fishing, and if can be confirmed that they are fishing for or have retained groundfish, that vessel is issued a citation. For the VMS system, an emergency message is sent from the VMS system vendor to NMFS if any vessel's VMS unit does not transmit position information for a certain amount of time. The owners of these vessels are immediately notified, and their status (either underway or in port) is confirmed by state or federal enforcement agents.

## 7.2 The Efficiency-shift

Section 6 demonstrates that as DAS trades are made, regardless of how those trades are predicted, nominal fishing effort will shift from less efficient to more efficient operators. The extent of this shift varies depending on how trades are analyzed. Appendices N and P attempt to investigate the impact of this efficiency-shift relative to other causes of increased fishery output<sup>37</sup>. Appendices O and Q also yield some insight into the magnitude of this shift. Based on these four appendices,

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"individual" category was 136 DAS.

<sup>37</sup> The other primary cause of increased fishery output is higher fleet-wide DAS utilization.

it appears that the shift in vessel efficiencies as a result of DAS trading translates into between a 30-40% increase in the net output of the fishery.

This conclusion is consistent with initial reports from the Faroe Island IEQ program discussed in Section 2. ICES (2001) notes “that catchability would increase as a result of the implementation of the effort management system should not come as a surprise...it is well known on the Faroes that those involved in the [program] are trying to use as few days as possible, and to make the most use of the days that are used.” Furthermore, preliminary data indicates that “the fishing mortality on cod doubled....from 1995 to 1996, as did the catch.” Their observation is not unexpected based on the results of market simulations summarized in Section 6. The Faroe Islands IEQ program allows for un-scaled nominal effort trades between all vessels in their fishery<sup>38</sup>. Without a mechanism to scale nominal effort trades, it is easy to imagine efficiency shifts much greater than their observed 100% increase in landings. Scaling trades to predicted vessel output dramatically increases likelihood that unanticipated shifts in fleet efficiency could result in non-sustainable fishery yields.

The results of this investigation indicate that increases in fleet efficiency are of sufficient magnitude that overall reductions in DAS, beyond those which accompany DAS trades from less to more efficient vessels, are likely to be necessary. To accomplish this goal, two methods were investigated: overall reductions in DAS allocations, and a “conservation multiplier” on DAS trades.

Overall reductions in DAS allocations simply entail a percentage allocation decrease that is equal for all vessels. Predicted markets using various percentages of individual DAS allocation

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<sup>38</sup> All otter trawl vessels involved in this fishery are under 400 VHP.

reductions indicate that a fleet-wide DAS reduction of roughly 65% would be necessary to achieve a zero-increase in predicted fishery output. See Appendix O for detailed results.

A conservation multiplier is a multiplying factor applied to DAS trades where, for every quality-adjusted DAS sold, more would be bought and thus eliminated from the total allocation. Results of predicted market trades demonstrate similar conservation benefits to the overall reduction in DAS allocations markets, but the higher average price per DAS predicted is likely to stifle trades and limit the effectiveness of such a plan. See Appendix Q for detailed results.

### 7.3 Latent Days-At-Sea, History Permits and Zero-Use Days-At-Sea

The markets outlined in Section 6 predict decreases in total nominal effort allocations after trading, but, based on the assumption of 100% DAS utilization by buyers, dramatic increases in fleet-wide DAS utilization are likely. Based on the results discussed in Sections 6 and Appendices K-Q, the impact of this change in DAS utilization appears to be responsible for a majority of the predicted increase in total fishery output.

Zero-use and history permit DAS present a similar problem to the latent DAS included in the model markets. As discussed in Section 4, however, DAS in these two categories may account for up to 65% of all allocated DAS. Re-introduction of zero-use and history permit DAS into the fishery, either through a market-based system or due to increased anticipated revenues from the fishery, is therefore a primary concern going forward. Allowing unfettered re-introduction of such DAS into the tradable effort market would almost certainly increase fishery output well beyond sustainable levels.

Results of predicted trades demonstrate the utilization of latent DAS is a more significant problem for fishery output increases than the shift in vessel efficiencies. One option for reducing this impact is the prohibition of historically unused DAS (latent DAS) from market trades (Appendix N ). Results of sample markets indicate a substantial reduction in predicted increases in total fishery output through the elimination of latent DAS. A less draconian incarnation of this idea would be to scale latent DAS differently than active-use DAS, allowing, for example, latent DAS to re-enter the fishery at a rate of ten-to-one. See

Similar alternatives likely provide the most productive alternative for allowing zero-use and history permit DAS to re-enter the fishery. However, due to the vast reservoir of DAS that fall into these two categories, an annual limit on the re-entry of such DAS would appear necessary.

As noted in Section 1, government funds have been allocated to capacity reduction programs in the past. A similar program could be pursued based on the effort market approach. Of the 1,651 vessels allocated DAS, 730 have no recorded groundfish landings between 1995-2000. Using modeled output to predict groundfish revenues for these vessels, and the equilibrium market-clearing price for a quality-adjusted DAS of \$0.4053, it is possible to predict expected groundfish revenues for these vessels. The SPF and OLS models are both used for expected output. The SPF approach, it should be noted, will yield a higher and therefore more generous predicted output than the OLS model. A 10-year timeframe for anticipated revenues and a 7% discount rate are used. The following table summarizes costs associated with government purchase of 100% of the total DAS allocated to these 730 vessels, which represent the zero-use and history permit DAS. Purchases at various percentages of the total MCP are investigated.

Table 7.1: Summary of costs for market-based purchase of zero-use and history permit DAS

| % of MCP | Total cost of DAS purchase, SPF output | Average cost per vessel, SPF output | Total cost of DAS purchase, OLS output | Average cost per vessel, OLS output |
|----------|--|-------------------------------------|--|-------------------------------------|
| .1       | \$38,995,922.19                        | \$53,419.00                         | \$28,998,315.27                        | \$39,723.64                         |
| .2       | \$77,091,502.82                        | \$105,604.72                        | \$52,569,244.61                        | \$72,012.59                         |
| .3       | \$115,187,083.46                       | \$157,790.45                        | \$76,140,173.94                        | \$104,301.53                        |
| .4       | \$153,282,664.09                       | \$209,976.18                        | \$99,711,103.27                        | \$136,590.48                        |
| .5       | \$191,378,244.73                       | \$262,161.90                        | \$123,282,032.60                       | \$168,879.42                        |
| 1.0      | \$381,856,147.90                       | \$523,090.54                        | \$241,136,679.26                       | \$330,324.14                        |

One potential solution based on this approach is for a government purchase of all zero-use and history permit DAS at a pre-determined percentage of whatever market-clearing price results from market trades.

#### 7.4 Consolidation

Market-enlisting management regimes have been shown to encourage fleet consolidation (NRC 1999), and the markets investigated here are no different. In fact, one of the most striking results to come from the predicted trade markets is the substantial fleet consolidation accompanying all DAS trades. In circumstances where fleet decentralization has been considered a priority for political or socio-economic reasons, policy makers have set limits on the amount of consolidation permitted<sup>39</sup>. These limits frequently take the form of maximum quota share allocations for any one person, corporation or entity, in keeping with the National Standards set forth in the MFCMA (Appendix C). In the case of these markets, a limit of 180 DAS was selected as a maximum for individual DAS allocations, but the choice of individual DAS maximum has a large impact on predicted fleet consolidation. MCP-based trades, using a \$250 profit/loss threshold, give the following results for different maximum DAS allocations:

Table 7.2: Summary of trades at different DAS maximum allocations, \$250 profit/loss threshold

<sup>39</sup> Three of the four domestic ITQ programs have such limits in place, the exception being the surf clam/ocean quahog fishery on the Atlantic coast (NRC 1999).

| Maximum Individual DAS Allocation | MCP    | Avg. Price Paid per DAS | # Sellers | # Buyers | Mean Residual Ratio-Sellers | Mean Residual Ratio-Buyers | Anticipated Increase in Fishery Total Output | Change in Net DAS Allocated | Change in Final Fleet Size |
|-----------------------------------|--------|-------------------------|-----------|----------|-----------------------------|----------------------------|--|-----------------------------|----------------------------|
| 106                               | 0.1891 | \$627.38                | 118       | 521      | 0.23855                     | 0.75583                    | 16.72%                                       | -35.27%                     | -0.20%                     |
| 136                               | 0.3348 | \$1,037.01              | 262       | 453      | 0.32497                     | 0.85005                    | 61.87%                                       | -27.79%                     | -23.73%                    |
| 152                               | 0.3855 | \$1,124.97              | 319       | 428      | 0.35527                     | 0.88281                    | 83.84%                                       | -23.75%                     | -33.59%                    |
| 180                               | 0.4564 | \$1,300.97              | 410       | 374      | 0.39769                     | 0.92020                    | 102.29%                                      | -21.09%                     | -45.34%                    |
| 200                               | 0.4938 | \$1,407.47              | 457       | 338      | 0.41940                     | 0.94523                    | 109.15%                                      | -20.76%                     | -50.67%                    |
| 230                               | 0.5425 | \$1,553.70              | 502       | 290      | 0.43907                     | 0.97922                    | 114.34%                                      | -21.82%                     | -55.65%                    |
| 260                               | 0.5751 | \$1,631.16              | 539       | 260      | 0.45489                     | 1.00464                    | 121.01%                                      | -20.76%                     | -59.76%                    |

Furthermore, this predicted fleet-wide consolidation is exacerbated by conservation measures such as overall fleet-wide reductions in DAS allocations, the conservation multiplier, and the elimination of latent DAS from the market. It is likely that, should policy makers chose maintaining fleet decentralization as a primary objective, implementation of a market-based regime may require severe restrictions on market trades. These restrictions may or may not dilute both the economic and regulatory efficiency benefits derived from such a system.

It bears noting, however, that when current rates of DAS utilization are taken into account the fleet is not as de-centralized as it may at first appear. The following table summarizes historical DAS utilization rates for the data set used in market trades.

Fig 7.2: Historical DAS utilization rates

| Historical DAS Utilization Rate | # Vessels |
|---------------------------------|-----------|
| >10%                            | 807       |
| >20%                            | 639       |
| >30%                            | 534       |
| >40%                            | 420       |
| >50%                            | 354       |
| >60%                            | 299       |
| >70%                            | 241       |
| >80%                            | 181       |
| >90%                            | 125       |

It is not surprising, then, that those vessels historically fishing only a small portion of their DAS allocations would be likely to sell under a market system.

## 7.5 Summary

Two significant conservation issues arise when analyzing market-based effort trades: shifting nominal DAS from less to more efficient vessels, and increases in fleet-wide DAS utilization rates. Based on results of various markets investigated, both issues, if unchecked, are highly likely to raise output from the fishery beyond sustainable levels. The use of fleet-wide reductions in DAS allocations and a conservation multiplier on DAS trades were investigated as potential methods for constraining output while allowing for the efficiency benefits produced by DAS trades. These tools are a necessary component if a tradable DAS program is to meet its economic and regulatory efficiency goals. Additionally, the use of market-based trades offers policy makers a valuable tool for the removal of zero-use and history permit DAS from the fishery.

All permutations of market-based trades result in consolidation of the fishing fleet. This consolidation is largely through the elimination of part-time fisherman predicted to be sellers based on these markets. Maximum allocation of DAS has a substantial bearing on predicted fleet consolidation. However, it is important to note that the size of the “active” groundfish fishing fleet is likely to shrink very little.

Increases in fleet efficiency are an almost certain result of market-based effort trades. The consequent overall increase in fishery output must be addressed, but the economic benefits of the efficiency gains are significant.

## Appendix A: Glossary of Abbreviations and Acronyms

|     |                             |
|-----|-----------------------------|
| CCF | Capital Construction Fund   |
| CLF | Conservation Law Foundation |

|       |   |
|-------|---|
| CPUE  | Catch Per Unit Effort   |
| DAS   | Days-At-Sea   |
| EEZ   | Exclusive Economic Zone   |
| F     | Fishing mortality   |
| FCMA  | Fishery Conservation and Management Act (1976)                  |
| FMP   | Fishery Management Plan   |
| GOM   | Gulf of Maine   |
| GTONS | Gross Tonnage   |
| IEQ   | Individual Effort Quota   |
| IFQ   | Individual Fish Quota   |
| ITQ   | Individual Transferable Quota                                   |
| LEN   | Length  |
| MCP   | Market Clearing Price   |
| MFCMA | Magnuson-Stevens Fishery Conservation and Management Act (1996) |
| NEFMC | New England Fisheries Management Council                        |
| NEFSC | Northeast Fisheries Science Center                              |
| NMFS  | National Marine Fisheries Service                               |
| OLS   | Ordinary Least Squares  |
| PPD   | Profit Per Day  |
| SFA   | Sustainable Fisheries Act (1996)                                |
| SPF   | Stochastic Production Frontier                                  |
| TAC   | Total Allowable Catch   |
| VHP   | Vessel Horsepower   |

## Appendix B: Summary of Notations

Table B-1: Summary of notations used (unless specified within brackets, variables are without units)

|               |   |
|---------------|---|
| $Y$           | Output, either in pounds of fish ( $Y_{\text{lbs}}$ ) or dollars ( $Y_{\$}$ ) |
| $Y^*$         | Predicted output  |
| $E$           | nominal fleet fishing effort (DAS)  |
| $A$           | stock abundance   |
| $q$           | vessel catchability coefficient   |
| $K$           | Capital   |
| $L$           | Labor   |
| $T$           | Technology  |
| $NDX$         | Non-discretionary inputs  |
| $\varepsilon$ | Error term, or residual   |
| $\beta$       | Residual Ratio  |
| $\alpha$      | Quality-adjusted DAS  |
| $p$           | Price per unit of quality-adjusted DAS (\$)                                   |
| $MCP$         | Market-clearing price (\$)  |
| $d_{\$}$      | Price per unit DAS (\$)   |

## **APPENDIX C: NATIONAL STANDARDS FOR FISHERY MANAGEMENT**

Magnuson-Stevens Fishery Conservation and Management Act

Public Law 94-265

As amended through October 11, 1996

SEC. 301, 16 U.S.C. 1851

NATIONAL STANDARDS FOR FISHERY

CONSERVATION AND MANAGEMENT

IN GENERAL-- Any fishery management plan prepared, and any regulation promulgated to implement any such plan, pursuant to this title shall be consistent with the following national standards for fishery conservation and management:

- (1) Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry.
- (2) Conservation and management measures shall be based upon the best scientific information available.
- (3) To the extent practicable, an individual stock of fish shall be managed as a unit throughout its range, and interrelated stocks of fish shall be managed as a unit or in close coordination.
- (4) Conservation and management measures shall not discriminate between residents of different States. If it becomes necessary to allocate or assign fishing privileges among various United States fishermen, such allocation shall be (A) fair and equitable to all such fishermen; (B) reasonably calculated to promote conservation; and (C) carried out in such manner that no particular individual, corporation, or other entity acquires an excessive share of such privileges.

(5) Conservation and management measures shall, where practicable, consider efficiency in the utilization of fishery resources; except that no such measure shall have economic allocation as its sole purpose.

(6) Conservation and management measures shall take into account and allow for variations among, and contingencies in, fisheries, fishery resources, and catches.

(7) Conservation and management measures shall, where practicable, minimize costs and avoid unnecessary duplication.

(8) Conservation and management measures shall, consistent with the conservation requirements of this Act (including the prevention of overfishing and rebuilding of overfished stocks), take into account the importance of fishery resources to fishing communities in order to (A) provide for the sustained participation of such communities, and (B) to the extent practicable, minimize adverse economic impacts on such communities.

(9) Conservation and management measures shall, to the extent practicable, (A) minimize bycatch and (B) to the extent bycatch cannot be avoided, minimize the mortality of such bycatch.

(10) Conservation and management measures shall, to the extent practicable, promote the safety of human life at sea.

## **APPENDIX D: DATA ACQUISITION**

The National Marine Fisheries Service's Northeast Fisheries Science Center (NEFSC) provided the data used for capacity utilization estimations. Fisheries data at the individual vessel/trip level are confidential but can be accessed for research purposes via a data access agreement as stipulated in the Magnuson Stevens Fisheries Management and Conservation Act. The Act limits data access to members of the New England Regional Management Council (NEFMC), National Marine Fisheries Service (NMFS), and academic researchers from State institutions. Brown University, as a private institution, does not qualify under these conditions, so creative measures were employed to obtain access to the necessary data.

During the preliminary stages of my research, I was introduced to Dr. Eric Thunberg of the NEFSC Social Sciences branch. Dr. Thunberg was instrumental in helping me form my thesis and guiding me along a path that at times became quite complicated. It was not clear initially exactly which data would be necessary to conduct my investigation. The scope and volume of data necessary meant that it was not practical (or desirable for either party) to have NEFSC staff perform the data extraction. To address both this and the regulatory roadblock of Brown's private status, Dr. Thunberg arranged an unpaid internship for me at the NEFSC. Brown University was still considered to be supervising my work, but the internship cleared the "private institution" hurdle.

The data access agreement was negotiated with Eugene Heyerdahl of the NEFSC. After extensive examination by the legal departments of both Brown and the NEFSC, it was signed by myself, Dr. Heyerdahl, Rusty Russell, Dr. Michael Sissenwine (NEFSC Director) and Brown University Associate Dean Crossgrove.

The agreement specified access to all commercial fisheries landings, logbook and dealer data for a one-year time period, beginning roughly on December 1, 2001. I was afforded access to the NEFSC intra-net and all databases via a LAN connection through a personal laptop. Desk space is at a premium at the NEFSC building and I was assigned to share a desk with Leslie-Ann McGee of the New England Fisheries Management Council. This arrangement worked well, as Leslie-Ann was courteous in keeping me informed of days when she was out of the office. I was able to access data on average every Friday and every other Wednesday. For a few weeks around the holidays I was afforded daily access to data, and these times were critical to my investigation.

## APPENDIX E: DESCRIPTION AND DISCUSSION OF AVAILABLE DATA

### E.0 Data Overview

Fisheries data is contained in 26 separate Oracle databases. Access to the raw data is through SQL. Querying multiple databases simultaneously and performing data analysis requires writing programs in the SAS language.

Data is parsed in several ways. First, there are three time periods and nine data types (below).

Table E-1: Data Categories and Time Series for commercial fisheries data

| DATA CONTENT     | 1994-Present Tables | 1982-1993 | 1964-1981  |
|------------------|---------------------|-----------|------------|
| Vessel Table     | CFVESSyr            | MSTRVESS  | MSTRVESS   |
| Detail Trip      | CFDETTyr            | WODETTyr  | WOLANDTyr  |
| Detail Species   | CFDETSyr            | WODETSyr  | WOLANDSyr  |
| Summary Trip     | CFSUMTyr            | WOSUMTyr  | ----       |
| Summary Species  | CFSUMSyr            | WOSUMSyr  | ----       |
| Length Frequency | CFLENYr             | WOLENYr   | WOLENYr    |
| Age Data         | CFAGEyr             | WOAGEyr   | WOAGEyr    |
| Discard Species  | CFDISCyr            | WODISCyr  | ----       |
| Interview Data   | ----                | ----      | INTVCRD3yr |

Within each of these individual databases are between 5 and 35 column headings covering different aspects of the data. All data is entered by Species, with Date, Vessel and other descriptive info contained within the species record. The exception are the three Vessel Table's, which contain detailed information on all permitted fishing vessels. It is necessary to combine the information found in several databases by searching for landings of individual species, then specifying individual vessels. This constructs a "trip record" for each vessel, which can be viewed and analyzed.

For the 1994-Present time series, there are two distinctly different data sets available. The first is called "dealer data," which is data reported to the National Marine Fisheries Service by all

permitted fish dealers. They record (among other data points) the date, amount and size of each species, average price paid, and vessel from which the product was offloaded. The second data set is called “Vessel Trip Report” (VTR) data. The VTR is a summary of each fishing trip that is filled out by vessel captains prior to landing. It contains the area where the fish were caught, amounts of each species landed, the departure and landing date for the trip, and the number of crew on board. VTR data and dealer data have been compared by various NEFSC staff who have found that, on average, the total reported landings of both data sets (dealer data and VTR) match up very well while individual trip-level landings show more variability. There are many reasons for this, but one of the most likely is that fisherman frequently offload to several dealers and in several ports; it can therefore be difficult or impossible to construct a complete “trip record” from dealer data. For investigations focusing on total landings, but not dependant upon matching those landings to specific vessel/trips, the literature has shown that dealer data is preferred. Due to the difficulty of constructing accurate “trip records,” VTR data is preferred when specific vessel/trip data is necessary. I chose to use the VTR data for this reason.

## E.1 Time Series

For this investigation I wanted to look at data from two different time-series. I chose a data set from 1989-1993 for my first time series, and a data set from 1995-2000 for my second. There are several differences in the prosecution of the groundfish fishery between these two time-series, as limited access, vessel size and horsepower restrictions, year-round closed areas, and Days-At-Sea were implemented in 1994. For this reason I felt that the 1989-1993 time-series might yield a more accurate picture of actual fishing effort, unconstrained by the newer regulations. The second time-series, 1995-2000, was utilized to analyze actual fishing effort under current regulatory conditions—an important aspect of the study, as fisheries regulation has seldom shown to grow less complex over time. The 1995-2000 time series encompassed more vessels, and

certainly captured observed outputs for a larger proportion of active fishing vessels, and therefore was utilized in assessing the tradable effort program.

## E.2 Description of Data Used

The two data time-series are further classified as either data sets, for the cross-sectional data used in the OLS models, or data panels, which were used in the SPF models. The cross-sectional data includes all vessels that landed groundfish (subject to the exclusion rules specified in Appendix G) in any one year. The panel data includes all vessels that landed groundfish in each of the years in the time-series.

Table E-2: Description of 1989-1993 Time-Series Data

|                                       | <b>Cross-sectional Data Set</b> | <b>Panel Data Set</b> |
|---------------------------------------|---------------------------------|-----------------------|
| <b>Number of Vessels</b>              | <b>689</b>                      | <b>422</b>            |
| <b>Mean Days Absent/Year</b>          | <b>78.2*</b>                    | <b>108.1</b>          |
| Std Dev                               | 70.6*                           | 71.7                  |
| Max                                   | 246.4*                          | 246.4                 |
| Min                                   | 5.2*                            | 5.6                   |
| <b>Mean Observed Revenue/Day (\$)</b> | <b>\$ 1,356.42</b>              | <b>\$ 1,455.29</b>    |
| Std Dev                               | \$ 749.27                       | \$ 746.73             |
| Max                                   | \$ 6101.65                      | \$ 6101.65            |
| Min                                   | \$ 122.82                       | \$ 147.47             |
| <b>Mean Horsepower (hp)</b>           | <b>424.6</b>                    | <b>431.7</b>          |
| Std Dev                               | 209.0                           | 187.9                 |
| Max                                   | 2250                            | 1250                  |
| Min                                   | 110                             | 110                   |
| <b>Mean Gross Tonnage (tons)</b>      | <b>84.0</b>                     | <b>89.8</b>           |
| Std Dev                               | 54.5                            | 52.82                 |
| Max                                   | 250                             | 250                   |
| Min                                   | 5                               | 8                     |
| <b>Mean Vessel Length (ft)</b>        | <b>64.5</b>                     | <b>66.5</b>           |
| Std Dev                               | 16.8                            | 15.34                 |
| Max                                   | 165                             | 120                   |
| Min                                   | 31                              | 34                    |

\*based upon average over the five-year period. The data does not show how many years each of the individual vessels actively fished and how many they did not; therefore, these numbers are for reference only and do not reflect actual values for this fleet.

Table E-3: Description of 1995-2000 Time-Series Data

|  | <b>Cross-sectional Data Set</b> | <b>Panel Data Set</b> |
|--|---------------------------------|-----------------------|
|--|---------------------------------|-----------------------|

|                                       |                    |                    |
|---------------------------------------|--------------------|--------------------|
| <b>Number of Vessels</b>              | <b>1100</b>        | <b>504</b>         |
| <b>Mean Days Absent/Year</b>          | <b>42.8*</b>       | <b>64.3</b>        |
| Std Dev                               | 35.6*              | 38.8               |
| Max                                   | 179.0*             | 179.0              |
| Min                                   | 5.0*               | 5.6                |
| <b>Mean Observed Revenue/Day (\$)</b> | <b>\$ 1,637.57</b> | <b>\$ 1,706.65</b> |
| Std Dev                               | \$ 1,135.49        | \$ 1,103.34        |
| Max                                   | \$ 9,054.11        | \$ 7,382.14        |
| Min                                   | \$ 7.05            | \$ 20.64           |
| <b>Mean Horsepower (hp)</b>           | <b>404.5</b>       | <b>387.8</b>       |
| Std Dev                               | 211.3              | 184.3              |
| Max                                   | 2000               | 2000               |
| Min                                   | 54                 | 54                 |
| <b>Mean Gross Tonnage (tons)</b>      | <b>59.3</b>        | <b>58.0</b>        |
| Std Dev                               | 54.6               | 50.9               |
| Max                                   | 258                | 199                |
| Min                                   | 4                  | 4                  |
| <b>Mean Vessel Length (ft)</b>        | <b>unk</b>         | <b>unk</b>         |
| Std Dev                               | unk                | unk                |
| Max                                   | unk                | unk                |
| Min                                   | unk                | unk                |

## APPENDIX F: SAS CODE

### F.0 Sample 1989-1993 Time-Series Code

The basic data was extracted in two parts. The first part created a .dat file for each individual year containing variables for vessel name, vessel permit number, year, total groundfish revenue, groundfish revenue per day, total other revenue, other revenue per day, days absent, days fished, gross tons, length, horsepower and age. The following is the SAS program for extracting the 1989 data.

```
proc sql;

  connect to oracle;
  %put &sqlxmsg;
  %put &sqlxrc;

  create view sumland
  as select docn, vessel, spplndlb, spplivlb, sppvalue, nespp3, area, month, day,
  port, negear
  from connection to oracle
  (select docn, to_number (vessel) vessel, spplndlb, spplivlb, sppvalue, nespp3,
  area, month, day, port, negear
  from wodets89 where negear = 50
  );

  create view detland
  as select docn, vessel, area, month, day, port, negear, da, df
  from connection to oracle
  (select docn, to_number (vessel) vessel, area, month, day, port,
  negear, da, df
  from wodett89 where negear = 50
  );

  create view vessel
  as select vp_num, ves_name, gtons, len, vhp, blt
  from connection to oracle
  (select to_number (vp_num) vp_num, ves_name, gtons, len, vhp, blt
  from vps_vessel where ap_year = 1990
  );

  disconnect from oracle;
  %put &sqlxmsg;
  %put &sqlxrc;
  quit;

data vess; set vessel;
proc sort; by vp_num;
data vess2; set vess; by vp_num;
if first.vp_num;
age = (1989
-blt)+1;
vessel = vp_num;
proc sort; by vessel;
```

```

data one; set sumland;
if vessel in('190998', '290998', '390998', '000000', '490998') then delete;
proc sort; by vessel docn month day port;

if nespp3 in(81, 120, 122, 123, 124, 125, 147, 153, 269, 240) then do;
ground = spplndlb;
gfval = sppvalue;
end;
if nespp3 not in(81, 120, 122, 123, 124, 125, 147, 153, 269, 240) then do;
other = spplndlb;
othval = sppvalue;
end;
proc sort; by vessel docn month day port;
proc means noprint; by vessel docn month day port;
var ground gfval other othval;
id df da;
output out = new sum=;

/* ***Adjust revenue for 1993 dollars (PPI)*** */

data new2; set new;
if month = 1 then do;
gfindex = gfval * .891;
othindex = othval * .891;
end;

if month = 2 then do;
gfindex = gfval * .897;
othindex = othval * .897;
end;

if month = 3 then do;
gfindex = gfval * .9;
othindex = othval * .9;
end;

if month = 4 then do;
gfindex = gfval * .907;
othindex = othval * .907;
end;

if month = 5 then do;
gfindex = gfval * .914;
othindex = othval * .914;
end;

if month = 6 then do;
gfindex = gfval * .914;
othindex = othval * .914;
end;

if month = 7 then do;
gfindex = gfval * .912;
othindex = othval * .912;
end;

if month = 8 then do;
gfindex = gfval * .909;
othindex = othval * .909;
end;

if month = 9 then do;
gfindex = gfval * .914;
othindex = othval * .914;
end;

if month = 10 then do;
gfindex = gfval * .919;
othindex = othval * .919;
end;

```

```

if month = 11 then do;
gfindex = gfval * .92;
othindex = othval * .92;
end;

if month = 12 then do;
gfindex = gfval * .926;
othindex = othval * .926;
end;
proc sort; by vessel docn month day port;
proc means noprint; by vessel docn month day port;
var ground gfindex other othindex;
id df da;
output out = new3 sum =;

/*****/

data new4; set new3;
if ground > 0;
if ground/sum(ground, other) > 0.4;
proc sort; by vessel;
proc means noprint; by vessel;
var ground gfindex other othindex df da;
output out = stuff sum=;
/*****/

data stuff2; set stuff;
landed = 1;
proc sort; by vessel;

data last; merge stuff2 vess2; by vessel;
if landed = 1;
/*****/

data final; set last;
year = 1989;

file 'vess89ppi.dat';
put ves_name 1-30 vessel year ground gfindex other othindex da df gtons len vhp age;

```

The second step is combining the data contained in each of the single-year .dat files. This was done in two ways. Panel data requires that only vessels generating revenue from groundfish in each of the years in the observed time-series be included. Cross-sectional data allows for all vessels that landed groundfish at any time during the observed time-series. The following is the SAS program which created the 1989-1993 time-series panel data. The result is a simple linear regression of vessel output (revenue per day) regressed on vessel horsepower and gross tonnage.

```

options linesize = 80;
data one;
infile 'vess93ppi.dat';
input ves_name $ 1-30 vessel yr93 gf93 gfind93 oth93 othind93 da93 df93 gt len vhp age;
if vhp > 50;
if gt > 3;
proc sort; by vessel;

data two;
infile 'vess92ppi.dat';

```

```

input ves_name $ 1-30 vessel yr92 gf92 gfind92 oth92 othind92 da92 df92 gt len vhp age;
if vhp > 50;
if gt > 3;
proc sort; by vessel;

data three;
infile 'vess91ppi.dat';
input ves_name $ 1-30 vessel yr91 gf91 gfind91 oth91 othind91 da91 df91 gt len vhp age;
if vhp > 50;
if gt > 3;
proc sort; by vessel;

data four;
infile 'vess90ppi.dat';
input ves_name $ 1-30 vessel yr90 gf90 gfind90 oth90 othind90 da90 df90 gt len vhp age;
if vhp > 50;
if gt > 3;
proc sort; by vessel;

data five;
infile 'vess89ppi.dat';
input ves_name $ 1-30 vessel yr89 gf89 gfind89 oth89 othind89 da89 df89 gt len vhp age;
if vhp > 50;
if gt > 3;
proc sort; by vessel;

data six; merge one two three four five; by vessel;
if yr93 = 1993 and yr92 = 1992 and yr91 = 1991 and yr90 = 1990 and yr89 = 1989 then panel
= 1;
if panel = 1;
data six2 (keep = vessel panel); set six;
if sum(da93, da92, da91, da90, da89) > 25;
proc sort; by vessel;

data seven; merge one six2; by vessel;
if panel = 1;

data eight; merge two six2; by vessel;
if panel = 1;

data nine; merge three six2; by vessel;
if panel = 1;

data ten; merge four six2; by vessel;
if panel = 1;

data eleven; merge five six2; by vessel;
if panel = 1;

data last; set seven eight nine ten eleven;

if yr93 = 1993 then do;
index93 = sum(gfind93, othind93);
indexda = index93/da93;
da = da93;
end;
if yr92 = 1992 then do;
index92 = sum(gfind92, othind92);
indexda = index92/da92;
da = da92;
end;
if yr91 = 1991 then do;
index91 = sum(gfind91, othind91);
indexda = index91/da91;
da = da91;
end;
if yr90 = 1990 then do;
index90 = sum(gfind90, othind90);
indexda = index90/da90;
da = da90;
end;

```

```

if yr89 = 1989 then do;
  index89 = sum(gfind89, othind89);
  indexda = index89/da89;
  da = da89;
end;

proc reg;
model indexda = vhp gt/vif collin;

```

## F.1 Sample 1995-2000 Time-Series Code

The .dat file creation program is as follows:

```

proc sql;

  connect to oracle;
  %put &sqlxmsg;
  %put &sqlxrc;

  create view yr96
  as select nespp3, permit, spplndlb, sppvalue, month, state
  from connection to oracle
  (select nespp3, to_number (permit) permit, spplndlb, sppvalue,
  to_number (month) month, state
  from cfsums1995 where negear = 50
  );

  create view vessel
  as select vp_num, ves_name, gtons, len, vhp, blt
  from connection to oracle
  (select to_number (vp_num) vp_num, ves_name, gtons, len, vhp, blt
  from vps_vessel where ap_year = 1995
  );

  disconnect from oracle;
  %put &sqlxmsg;
  %put &sqlxrc;
  quit;

  data vess; set vessel;
  proc sort; by vp_num;
  data vess2; set vess; by vp_num;
  if first.vp_num;
  age = (2000
  -blt)+1;
  vessel = vp_num;
  proc sort; by vessel;

  data one; set vess2;
  proc sort; by vessel;

  data rev96; set yr96;
  proc sort; by nespp3 month;
  proc means noprint; by nespp3 month;
  var sppvalue spplndlb;
  output out = p96 sum=;

  data price96; set p96;
  price = sppvalue/spplndlb;
  proc sort; by nespp3 month;

  data two; set barb.comm95;
  format newsail2 newlnd2 datetimel6.;
  dsail=datepart(datesail);
  dlnd=datepart(date1nd1);

```

```

newsail2=dhms(dsail,hoursail,minsail,secsail);
newlnd2=dhms(dlnd,hourlnd1,minlnd1,seclnd1);
month = month(dlnd);
day = day(dlnd);
da=((newlnd2-newsail2)+1)/(24*60*60);
df=((soakhrs+soakmin/60)*nhhaul)/24;
    if minsail = 'pm' then delete;
    if minlnd1 = 'pm' then delete;
    if da > 0 and da <= 1 then da = 1;
    if da > 300 then delete;
    if nemarea = '?' then delete;
proc sort; by nespp3 month;

data three; merge price96 two; by nespp3 month;
value = keptlb*price;
vessel = permit;

if nespp3 in(81, 120, 122, 123, 124, 125, 147, 153, 269, 240) then gf = 1;
if gf = 1 then do;
gfval = value;
end;
if gf ne 1 then do;
othval = value;
end;

/* ***Adjust revenue for 1993 dollars (PPI)*** */

if month = 1 then do;
gfindex = gfval * 1.017;
othindex = othval * 1.017;
end;

if month = 2 then do;
gfindex = gfval * 1.020;
othindex = othval * 1.020;
end;

if month = 3 then do;
gfindex = gfval * 1.021;
othindex = othval * 1.021;
end;

if month = 4 then do;
gfindex = gfval * 1.024;
othindex = othval * 1.024;
end;

if month = 5 then do;
gfindex = gfval * 1.025;
othindex = othval * 1.025;
end;

if month = 6 then do;
gfindex = gfval * 1.025;
othindex = othval * 1.025;
end;

if month = 7 then do;
gfindex = gfval * 1.026;
othindex = othval * 1.026;
end;

if month = 8 then do;
gfindex = gfval * 1.025;
othindex = othval * 1.025;
end;

if month = 9 then do;
gfindex = gfval * 1.027;
othindex = othval * 1.027;
end;

```

```

if month = 10 then do;
gfindex = gfval * 1.029;
othindex = othval * 1.029;
end;

if month = 11 then do;
gfindex = gfval * 1.032;
othindex = othval * 1.032;
end;

if month = 12 then do;
gfindex = gfval * 1.037;
othindex = othval * 1.037;
end;

proc sort; by idt;
proc means noprint; by idt;
var gfindex othindex;
id da vessel;
output out = four sum=;

data five; set four;
if gfindex = . then gfindex = 0;
if othindex = . then othindex = 0;
if gfindex/sum(gfindex, othindex) > .4;
proc sort; by vessel;

proc means noprint; by vessel;
var da gfindex othindex;
output out = stuff sum =;

data six; set stuff;
proc sort; by vessel;

data seven; merge six one; by vessel;
proc sort; by vessel;

data last; set seven;
year = 1995;

file 'year1995ppi.dat';
put ves_name $ 1-30 vessel year gfindex othindex da vhp gtons;

```

The modeling program is as follows:

```

options linesize = 80;
data one;
infile 'year1995ppi.dat';
input ves_name $ 1-30 vessel yr95 gfindex95 othindex95 da95 vhp gtons;
if gfindex95 = . then gfindex95 = 0;
if othindex95 = . then othindex95 = 0;
if da95 = . then da95 = 0;
if da95 > 0;
if vhp > 50;
if gtons > 3;
proc sort; by vessel;

data two;
infile 'year1996ppi.dat';
input ves_name $ 1-30 vessel yr96 gfindex96 othindex96 da96 vhp gtons;
if gfindex96 = . then gfindex96 = 0;
if othindex96 = . then othindex96 = 0;
if da96 = . then da96 = 0;
if da96 > 0;
if vhp > 50;

```

```

if gtons > 3;
proc sort; by vessel;

data three;
infile 'year1997ppi.dat';
input ves_name $ 1-30 vessel yr97 gfind97 othind97 da97 vhp gtons;
if gfind97 = . then gfind97 = 0;
if othind97 = . then othind97 = 0;
if da97 = . then da97 = 0;
if da97 > 0;
if vhp > 50;
if gtons > 3;
proc sort; by vessel;

data four;
infile 'year1998ppi.dat';
input ves_name $ 1-30 vessel yr98 gfind98 othind98 da98 vhp gtons;
if gfind98 = . then gfind98 = 0;
if othind98 = . then othind98 = 0;
if da98 = . then da98 = 0;
if da98 > 0;
if vhp > 50;
if gtons > 3;
proc sort; by vessel;

data five;
infile 'year1999ppi.dat';
input ves_name $ 1-30 vessel yr99 gfind99 othind99 da99 vhp gtons;
if gfind99 = . then gfind99 = 0;
if othind99 = . then othind99 = 0;
if da99 = . then da99 = 0;
if da99 > 0;
if vhp > 50;
if gtons > 3;
proc sort; by vessel;

data five2;
infile 'year2000ppi.dat';
input ves_name $ 1-30 vessel yr00 gfind00 othind00 da00 vhp gtons;
if gfind00 = . then gfind00 = 0;
if othind00 = . then othind00 = 0;
if da00 = . then da00 = 0;
if da00 > 0;
if vhp > 50;
if gtons > 3;
proc sort; by vessel;

data six; merge one two three four five five2; by vessel;
if yr95 = 1995 and yr96 = 1996 and yr97 = 1997 and yr98 = 1998 and yr99 = 1999 and yr00 =
2000 then panel = 1;
if panel = 1;
if sum(da95, da96, da97, da98, da99, da00) > 30;
data six2 (keep = vessel panel); set six;
proc sort; by vessel;

data seven; merge one six2; by vessel;
if panel = 1;

data eight; merge two six2; by vessel;
if panel = 1;

data nine; merge three six2; by vessel;
if panel = 1;

data ten; merge four six2; by vessel;
if panel = 1;

data eleven; merge five six2; by vessel;
if panel = 1;

data twelve; merge five2 six2; by vessel;

```

```

if panel = 1;

data last; set seven eight nine ten eleven twelve;

/* ***aggregate all years by vessel*** */

if yr95 = 1995 then do;
  index95 = sum(gfind95, othind95);
  indexda = index95/da95;
  year = yr95;
  da = da95;
end;
if yr96 = 1996 then do;
  index96 = sum(gfind96, othind96);
  indexda = index96/da96;
  year = yr96;
  da = da96;
end;
if yr97 = 1997 then do;
  index97 = sum(gfind97, othind97);
  indexda = index97/da97;
  year = yr97;
  da = da97;
end;
if yr98 = 1998 then do;
  index98 = sum(gfind98, othind98);
  indexda = index98/da98;
  year = yr98;
  da = da98;
end;
if yr99 = 1999 then do;
  index99 = sum(gfind99, othind99);
  indexda = index99/da99;
  year = yr99;
  da = da99;
end;
if yr00 = 2000 then do;
  index00 = sum(gfind00, othind00);
  indexda = index00/da00;
  year = yr00;
  da = da00;
end;

proc reg;
model indexda = vhp gtons/vif collin;

```

## Appendix G: Model Results

### G.0 Exclusion Rules

To best capture the predicted output of one day at sea, certain constraints were placed on the data in order to eliminate outliers not necessarily representative of true groundfish fishing vessels.

Vessels meeting the following criteria were excluded from the data set:

- Groundfish landings accounting for less than 40% of the value of their trip
- Documented engine sizes smaller than 50 VHP
- Registered GRT less than three gross tons
- Fishing less than 25 days total in a five year period (1989-1993), or less than 30 days total in a six year period (1995-2000)

## G.1 1989-1993 Time-Series Results

The final results for the two primary models (OLS and SPF) are included below.

Fig G-1: Final OLS Model, 1989-1993 Time-Series (Cross-Sectional Data)

```

The SAS System
Model: MODEL1
Dependent Variable: INDEXDA
    
```

| Analysis of Variance |     |                |              |         |        |
|----------------------|-----|----------------|--------------|---------|--------|
| Source               | DF  | Sum of Squares | Mean Square  | F Value | Prob>F |
| Model                | 2   | 237939473.47   | 118969736.74 | 550.289 | 0.0001 |
| Error                | 686 | 148309842.21   | 216195.10527 |         |        |
| C Total              | 688 | 386249315.69   |              |         |        |

|          |            |          |        |
|----------|------------|----------|--------|
| Root MSE | 464.96785  | R-square | 0.6160 |
| Dep Mean | 1356.41679 | Adj R-sq | 0.6149 |
| C.V.     | 34.27913   |          |        |

| Parameter Estimates |    |                    |                |                       |           |
|---------------------|----|--------------------|----------------|-----------------------|-----------|
| Variable            | DF | Parameter Estimate | Standard Error | T for H0: Parameter=0 | Prob >  T |
| INTERCEP            | 1  | 229.837613         | 40.14705452    | 5.725                 | 0.0001    |
| VHP                 | 1  | 1.613199           | 0.13467019     | 11.979                | 0.0001    |
| GT                  | 1  | 5.257720           | 0.51648901     | 10.180                | 0.0001    |

| Variance Inflation |    |            |
|--------------------|----|------------|
| Variable           | DF | Inflation  |
| INTERCEP           | 1  | 0.00000000 |
| VHP                | 1  | 2.52103883 |
| GT                 | 1  | 2.52103883 |

| Collinearity Diagnostics |            |                 |                   |              |             |  |
|--------------------------|------------|-----------------|-------------------|--------------|-------------|--|
| Number                   | Eigenvalue | Condition Index | Var Prop INTERCEP | Var Prop VHP | Var Prop GT |  |
| 1                        | 2.78452    | 1.00000         | 0.0225            | 0.0096       | 0.0140      |  |
| 2                        | 0.16600    | 4.09560         | 0.7186            | 0.0130       | 0.2541      |  |
| 3                        | 0.04947    | 7.50235         | 0.2589            | 0.9774       | 0.7319      |  |

Fig G-2: 1989-1993 Time-Series, Actual vs. Predicted Output

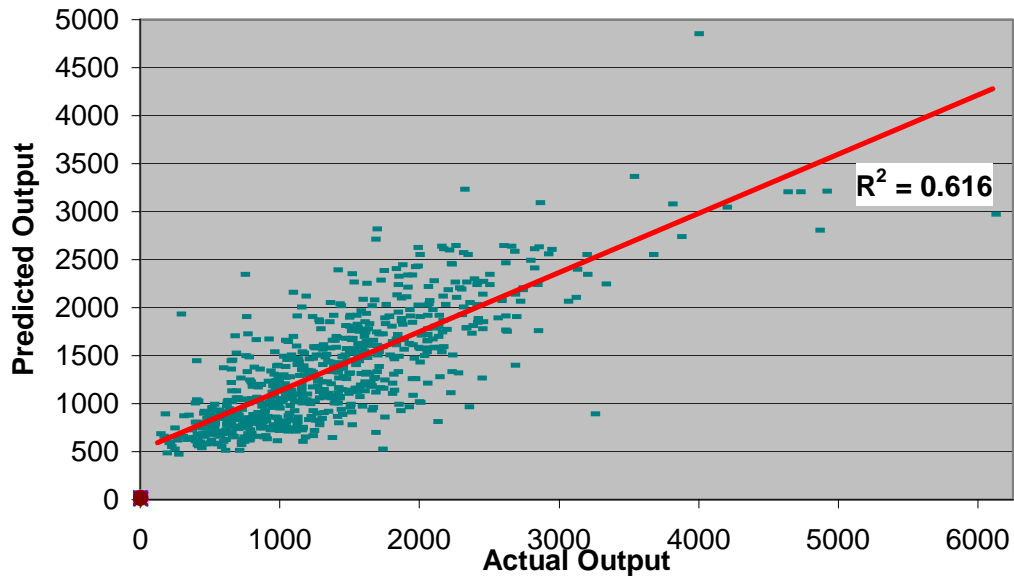


Fig G-3: Final SPF Model, 1989-1993 Time-Series (Panel Data)

```

Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file =      panelA.dat

Error Components Frontier (see B&C 1992)
The model is a production function
The dependent variable is not logged

the ols estimates are :

                coefficient      standard-error      t-ratio
beta 0          0.30840362E+03    0.29491132E+02    0.10457504E+02
beta 1          0.15241315E+01    0.10409718E+00    0.14641429E+02
beta 2          0.49792453E+01    0.37033403E+00    0.13445282E+02
sigma-squared   0.57841773E+05

log likelihood function =  -0.14561026E+05

the estimates after the grid search were :

beta 0          0.56938832E+03
beta 1          0.15241315E+01
beta 2          0.49792453E+01
sigma-squared   0.12587254E+06
gamma           0.85000000E+00
mu is restricted to be zero
eta is restricted to be zero
the final mle estimates are :

                coefficient      standard-error      t-ratio
beta 0          0.56939069E+03    0.10000000E+01    0.56939069E+03
beta 1          0.26849390E+01    0.10000000E+01    0.26849390E+01
beta 2          0.52089701E+01    0.10000000E+01    0.52089701E+01
sigma-squared   0.12587254E+06    0.10000000E+01    0.12587254E+06
gamma           0.99999999E+00    0.83267152E-07    0.12009537E+08
mu is restricted to be zero
eta is restricted to be zero

log likelihood function =  -0.13025119E+04

LR test of the one-sided error =  0.26517029E+05
with number of restrictions = 1
[note that this statistic has a mixed chi-square distribution]

number of iterations =      2

(maximum number of iterations set at :  100)

number of cross-sections =   422

number of time periods =     5

total number of observations =  2110

thus there are:      0 obsns not in the panel

```

## G.2 1995-2000 Time-Series Results

The final results for the two primary models (OLS and SPF) are included below.

Fig G-4: Final OLS Model, 1995-2000 Time-Series (Cross-Sectional Data)

```

The SAS System
Model: MODEL1
Dependent Variable: INDEXDA
    
```

| Analysis of Variance |      |                |              |         |        |
|----------------------|------|----------------|--------------|---------|--------|
| Source               | DF   | Sum of Squares | Mean Square  | F Value | Prob>F |
| Model                | 2    | 763354763.62   | 381677381.81 | 640.589 | 0.0001 |
| Error                | 1097 | 653617477.5    | 595822.67776 |         |        |
| C Total              | 1099 | 1416972241.1   |              |         |        |

|          |            |          |        |
|----------|------------|----------|--------|
| Root MSE | 771.89551  | R-square | 0.5387 |
| Dep Mean | 1637.57658 | Adj R-sq | 0.5379 |
| C.V.     | 47.13645   |          |        |

| Parameter Estimates |    |                    |                |                       |           |
|---------------------|----|--------------------|----------------|-----------------------|-----------|
| Variable            | DF | Parameter Estimate | Standard Error | T for H0: Parameter=0 | Prob >  T |
| INTERCEP            | 1  | 467.243591         | 51.26176580    | 9.115                 | 0.0001    |
| VHP                 | 1  | 1.194662           | 0.15935370     | 7.497                 | 0.0001    |
| GTONS               | 1  | 11.577416          | 0.61644884     | 18.781                | 0.0001    |

| Variance Inflation |    |                    |  |  |  |
|--------------------|----|--------------------|--|--|--|
| Variable           | DF | Variance Inflation |  |  |  |
| INTERCEP           | 1  | 0.00000000         |  |  |  |
| VHP                | 1  | 2.09213203         |  |  |  |
| GTONS              | 1  | 2.09213203         |  |  |  |

| Collinearity Diagnostics |            |                 |                   |              |                |  |
|--------------------------|------------|-----------------|-------------------|--------------|----------------|--|
| Number                   | Eigenvalue | Condition Index | Var Prop INTERCEP | Var Prop VHP | Var Prop GTONS |  |
| 1                        | 2.66919    | 1.00000         | 0.0248            | 0.0138       | 0.0262         |  |
| 2                        | 0.26423    | 3.17832         | 0.3788            | 0.0001       | 0.4264         |  |
| 3                        | 0.06658    | 6.33156         | 0.5963            | 0.9861       | 0.5473         |  |

Fig G-5: 1995-2000 Time-Series, Actual vs. Predicted Output

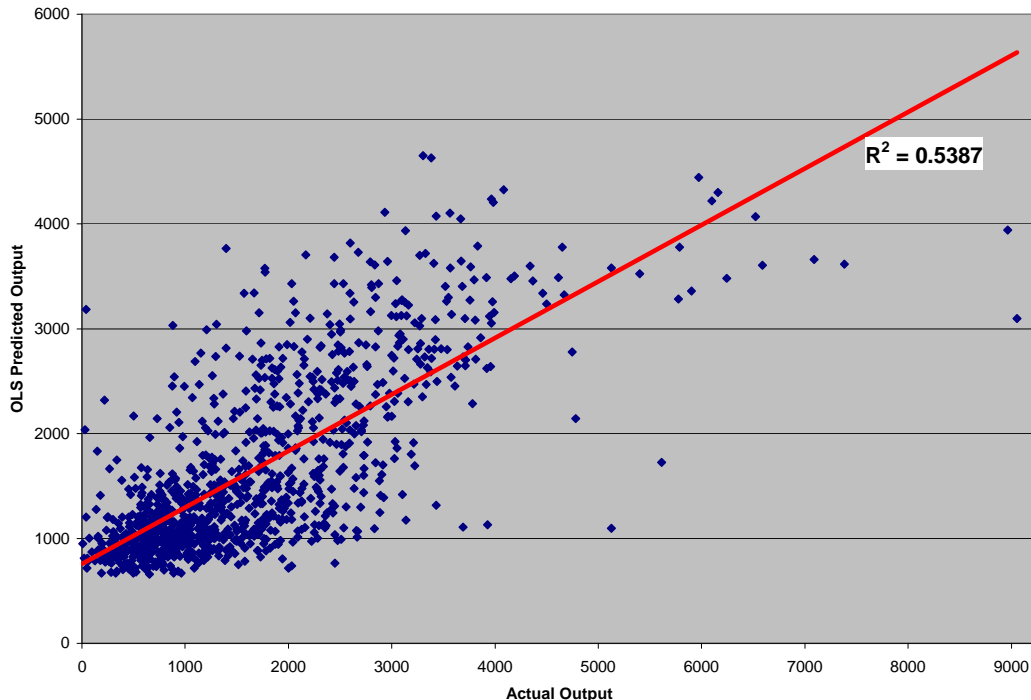


Fig G-6: Final SPF Model, 1995-2000 Time-Series (Panel Data)

```

Output from the program FRONTIER (Version 4.1c)
instruction file = terminal
data file =      panelB.dat

Error Components Frontier (see B&C 1992)
The model is a production function
The dependent variable is not logged

the ols estimates are :

                coefficient      standard-error      t-ratio
beta 0          0.30523064E+03    0.40116287E+02    0.76086463E+01
beta 1          0.16118723E+01    0.12450986E+00    0.12945740E+02
beta 2          0.13493322E+02    0.45069336E+00    0.29939030E+02
sigma-squared   0.87061404E+06

log likelihood function = -0.24968924E+05

the estimates after the grid search were :

beta 0          0.10285564E+04
beta 1          0.16118723E+01
beta 2          0.13493322E+02
sigma-squared   0.13929504E+07
gamma          0.59000000E+00
mu is restricted to be zero
eta is restricted to be zero

the final mle estimates are :

                coefficient      standard-error      t-ratio
beta 0          0.68954447E+03    0.65213991E+02    0.10573566E+02
beta 1          0.29096801E+01    0.21488487E+00    0.13540647E+02
beta 2          0.11635059E+02    0.76197231E+00    0.15269661E+02
sigma-squared   0.13929507E+07    0.10011536E+01    0.13913457E+07
gamma          0.59081074E+00    0.11695816E-01    0.50514710E+02
mu is restricted to be zero
eta is restricted to be zero

log likelihood function = -0.24703087E+05

LR test of the one-sided error = 0.53167333E+03
with number of restrictions = 1
[note that this statistic has a mixed chi-square distribution]

number of iterations = 12

(maximum number of iterations set at : 100)

number of cross-sections = 504
number of time periods = 6
total number of observatio= 3024

thus there are: 0 obsns not in the panel

```

### G.3 Functional Forms

After determining which variables to include (see Section 4), I experimented with several functional forms including log-log and trans-log. Modeles based on logged dependent variables are somewhat standard for econometric analysis (see Kumbhakar et. al 2000, Kennedy 1985).

The trans-log form especially has been used extensively for modeling fisheries outputs as a function of inputs (see Holland 1998, Holland 2000, Kirkley and Squires 1999). I rejected all log-based functional forms for both simplicity and goodness-of-fit. Note that while the panel data sets were used in the models below, the results were run based upon annual per-vessel output and the panel characteristic of the data set is irrelevant.

Fig G-7: Log-Log Model, 1989-1993 Time-Series (Panel Data)

```

The SAS System
Model: MODEL1
Dependent Variable: LNINDEX

```

| Analysis of Variance |      |                |             |         |        |
|----------------------|------|----------------|-------------|---------|--------|
| Source               | DF   | Sum of Squares | Mean Square | F Value | Prob>F |
| Model                | 2    | 412.16441      | 206.08220   | 979.629 | 0.0001 |
| Error                | 2107 | 443.24445      | 0.21037     |         |        |
| C Total              | 2109 | 855.40886      |             |         |        |

|          |         |          |        |
|----------|---------|----------|--------|
| Root MSE | 0.45866 | R-square | 0.4818 |
| Dep Mean | 7.10286 | Adj R-sq | 0.4813 |
| C.V.     | 6.45738 |          |        |

| Parameter Estimates |    |                    |                |                       |           |
|---------------------|----|--------------------|----------------|-----------------------|-----------|
| Variable            | DF | Parameter Estimate | Standard Error | T for H0: Parameter=0 | Prob >  T |
| INTERCEP            | 1  | 2.866611           | 0.16393134     | 17.487                | 0.0001    |
| LVNHP               | 1  | 0.422420           | 0.03782709     | 11.167                | 0.0001    |
| LVNLT               | 1  | 0.398517           | 0.02215296     | 17.989                | 0.0001    |

| Variance Inflation |    |                    |
|--------------------|----|--------------------|
| Variable           | DF | Variance Inflation |
| INTERCEP           | 1  | 0.00000000         |
| LVNHP              | 1  | 2.57002241         |
| LVNLT              | 1  | 2.57002241         |

| Collinearity Diagnostics |            |                 |                   |                |                |
|--------------------------|------------|-----------------|-------------------|----------------|----------------|
| Number                   | Eigenvalue | Condition Index | Var Prop INTERCEP | Var Prop LVNHP | Var Prop LVNLT |
| 1                        | 2.98421    | 1.00000         | 0.0004            | 0.0002         | 0.0012         |
| 2                        | 0.01455    | 14.32026        | 0.0932            | 0.0039         | 0.4486         |
| 3                        | 0.00123    | 49.19609        | 0.9064            | 0.9959         | 0.5502         |

Fig G-8: Log-Log Model, 1995-2000 Time-Series (Panel Data)

```

The SAS System
Model: MODEL1
Dependent Variable: LNINDEX

              Analysis of Variance
              Sum of      Mean
              Squares      Square      F Value      Prob>F

Source          DF          2          3021          3023
Model           2          889.82494    444.91247    1061.137     0.0001
Error          3021          1266.64223    0.41928
C Total        3023          2156.46717

              Root MSE          0.64752
              Dep Mean          7.15247
              C.V.              9.05306

              R-square          0.4126
              Adj R-sq         0.4122

              Parameter Estimates
              Parameter          Standard      T for H0:
              Estimate          Error      Parameter=0      Prob > |T|

Variable DF          INTERCEP 1          2.394415    0.18054571    13.262    0.0001
Variable DF          LNVHP 1          0.595624    0.03548696    16.784    0.0001
Variable DF          LNGTONS 1          0.348671    0.01486665    23.453    0.0001

              Variance
              Inflation

Variable DF          INTERCEP 1          0.00000000
Variable DF          LNVHP 1          1.61170237
Variable DF          LNGTONS 1          1.61170237

              Collinearity Diagnostics
              Condition      Var Prop      Var Prop      Var Prop
              Index      INTERCEP      LNVHP      LNGTONS

Number Eigenvalue          1.00000    0.0005    0.0004    0.0049
1          2.95596          8.36804    0.0249    0.0071    0.6932
2          0.04221          40.24843    0.9746    0.9926    0.3019
3          0.00182
    
```

Fig G-9: Trans-log Model, 1995-2000 Time-Series (Panel Data)

```

The SAS System
Model: MODEL1
Dependent Variable: LNINDEX

Analysis of Variance
Source              DF          Sum of Squares      Mean Square      F Value      Prob>F
Model                5          925.30064          185.06013        453.644      0.0001
Error              3018        1231.16653           0.40794
C Total             3023        2156.46717

Root MSE          0.63870      R-square          0.4291
Dep Mean          7.15247      Adj R-sq         0.4281
C.V.              8.92982

Parameter Estimates
Variable  DF      Parameter Estimate      Standard Error      T for H0:
                                           Parameter=0      Prob > |T|
INTERCEP  1      -1.281854          1.47246691          -0.871          0.3841
LNVHP     1       2.450635          0.53461255           4.584          0.0001
LNGTONS   1      -0.556353          0.18737415          -2.969          0.0030
LNVHPSQ   1      -0.177991          0.04996049          -3.563          0.0004
LNGTSQ    1       0.103917          0.01517175           6.849          0.0001
LNVHPGT   1       0.035384          0.03865848           0.915          0.3601

Variance Inflation
Variable  DF      Variance Inflation
INTERCEP  1          0.00000000
LNVHP     1       375.95097658
LNGTONS   1       263.13801927
LNVHPSQ   1       459.47997856
LNGTSQ    1        86.07147012
LNVHPGT   1       545.76150677

Collinearity Diagnostics
Number  Eigenvalue      Condition Index      Var Prop INTERCEP      Var Prop LNVHP      Var Prop LNGTONS      Var Prop LNVHPSQ      Var Prop LNGTSQ      Var Prop LNVHPGT
1        5.82833          1.00000          0.0000          0.0000          0.0000          0.0000          0.0000          0.0000          0.0000          0.0000          0.0000          0.0000          0.0000
2        0.16163          6.00505          0.0001          0.0000          0.0000          0.0001          0.0000          0.0064          0.0001          0.0000          0.0001          0.0007          0.0001
3        0.00869          25.89269          0.0021          0.0000          0.0000          0.0053          0.0025          0.0001          0.0007          0.0000          0.0001          0.0007          0.0007
4        0.00123          68.75033          0.0041          0.0002          0.0002          0.0725          0.0000          0.7358          0.0000          0.0000          0.7358          0.0269          0.0269
5        0.0001081        232.17524          0.0557          0.0020          0.0020          0.7250          0.0276          0.2574          0.0000          0.0000          0.2574          0.8480          0.8480
6        8.9568E-6         806.66969          0.9380          0.9978          0.9978          0.1971          0.9699          0.0003          0.0003          0.0003          0.0003          0.1242          0.1242
    
```

G.4 Combined Time-Series Results

I combined the two time-series in order to have a basis for comparison of the results of the individual time-series' models. This increased the degrees of freedom of the model, but, because the two time-series took place under different regulatory environments, I elected to focus on the data as broken down by time-series. Nonetheless, the results of the combined time-series data are reported as follows.

Fig G-10: Combined 1989-1993 and 1995-2000 Time-Series

```

The SAS System
Model: MODEL1
Dependent Variable: INDEXDA

                                Analysis of Variance

                                Sum of          Mean
                                Squares        Square      F
Source              DF
Value              Prob>F

Model                2 420196745.42 210098372.71
431.478             0.0001
Error               702 341822708.55 486926.93526
C Total            704 762019453.97

                                Root MSE        697.80150      R-square        0.5514
                                Dep Mean      1636.07830      Adj R-sq        0.5501
                                C.V.         42.65086

                                Parameter Estimates

                                Parameter      Standard      T for H0:
                                Estimate        Error        Parameter=0
Variable  DF
Prob > |T|

INTERCEP  1      275.957572    62.48639982      4.416
0.0001

```

|                          |        |            |            |               |
|--------------------------|--------|------------|------------|---------------|
| VHP                      | 1      | 1.891121   | 0.19739584 | 9.580         |
| 0.0001                   |        |            |            |               |
| GT                       | 1      | 8.769036   | 0.69481079 | 12.621        |
| 0.0001                   |        |            |            |               |
| Variance                 |        |            |            |               |
| Variable                 | DF     | Inflation  |            |               |
| INTERCEP                 | 1      | 0.00000000 |            |               |
| VHP                      | 1      | 2.03713712 |            |               |
| GT                       | 1      | 2.03713712 |            |               |
| Collinearity Diagnostics |        |            |            |               |
|                          |        | Condition  | Var Prop   | Var Prop      |
| Var Prop                 |        |            |            |               |
|                          | Number | Eigenvalue | Index      | INTERCEP VHP  |
| GT                       |        |            |            |               |
|                          | 1      | 2.72488    | 1.00000    | 0.0211 0.0115 |
| 0.0225                   |        |            |            |               |
|                          | 2      | 0.21694    | 3.54407    | 0.3940 0.0002 |
| 0.4518                   |        |            |            |               |
|                          | 3      | 0.05818    | 6.84345    | 0.5850 0.9883 |
| 0.5257                   |        |            |            |               |

### G.5 Year-Based Dummy Variables

I also experimented with dummy variables for different years to determine the significance of the year in model output.

For the 1989-1993 time-series, 1989 was used as the base year and 1992 was found to be the only year with parameter estimates similar to 1989. This result highlights the importance of factors other than those used in the model for predicting fishery output. For reasons explained in Section 4, once again, this does not pose a problem for my investigation.

Fig G-11: Year Dummy Variables, 1989-1993 Panel Data

```

The SAS System
Model: MODEL1
Dependent Variable: INDEXDA

                                Analysis of Variance

                                Sum of      Mean
                                Squares     Square     F
Source          DF          Value          Prob>F
Model           6  764940304.32  127490050.72
341.715        0.0001
Error          2103  784604943.94  373088.41842
C Total        2109  1549545248.3

                                Root MSE      610.80964      R-square      0.4937
                                Dep Mean      1444.73868      Adj R-sq      0.4922
                                C.V.         42.27821

                                Parameter Estimates

                                Parameter      Standard      T for H0:
                                Estimate         Error      Parameter=0
Variable  DF          Value          Prob > |T|
INTERCEP  1  178.633769  42.18432575  4.235
0.0001

```

|        |          |    |             |                          |          |
|--------|----------|----|-------------|--------------------------|----------|
|        | VHP      | 1  | 1.682135    | 0.11324296               | 14.854   |
| 0.0001 |          |    |             |                          |          |
|        | GT       | 1  | 5.664588    | 0.41188314               | 13.753   |
| 0.0001 |          |    |             |                          |          |
|        | DUM93    | 1  | -180.099495 | 42.08760400              | -4.279   |
| 0.0001 |          |    |             |                          |          |
|        | DUM92    | 1  | -40.278180  | 42.06059898              | -0.958   |
| 0.3384 |          |    |             |                          |          |
|        | DUM91    | 1  | 210.881937  | 42.05130932              | 5.015    |
| 0.0001 |          |    |             |                          |          |
|        | DUM90    | 1  | 110.045795  | 42.04986987              | 2.617    |
| 0.0089 |          |    |             |                          |          |
|        |          |    | Variance    |                          |          |
|        | Variable | DF | Inflation   |                          |          |
|        | INTERCEP | 1  | 0.00000000  |                          |          |
|        | VHP      | 1  | 2.68102298  |                          |          |
|        | GT       | 1  | 2.67794219  |                          |          |
|        | DUM93    | 1  | 1.60287286  |                          |          |
|        | DUM92    | 1  | 1.60081659  |                          |          |
|        | DUM91    | 1  | 1.60010954  |                          |          |
|        | DUM90    | 1  | 1.60000000  |                          |          |
|        |          |    |             | Collinearity Diagnostics |          |
|        |          |    | Condition   | Var Prop                 | Var Prop |

| Var Prop | Var Prop   | Var Prop | Var Prop |        |        |
|----------|------------|----------|----------|--------|--------|
| Number   | Eigenvalue | Index    | INTERCEP | VHP    | GT     |
| DUM93    | DUM92      | DUM91    | DUM90    |        |        |
| 1        | 3.61007    | 1.00000  | 0.0071   | 0.0044 | 0.0065 |
| 0.0082   | 0.0081     | 0.0080   | 0.0080   |        |        |
| 2        | 1.00010    | 1.89993  | 0.0000   | 0.0000 | 0.0000 |
| 0.2769   | 0.0087     | 0.0505   | 0.1633   |        |        |
| 3        | 1.00000    | 1.90002  | 0.0000   | 0.0000 | 0.0000 |
| 0.0161   | 0.1776     | 0.2598   | 0.0463   |        |        |
| 4        | 1.00000    | 1.90002  | 0.0000   | 0.0000 | 0.0000 |
| 0.0790   | 0.1880     | 0.0657   | 0.1671   |        |        |
| 5        | 0.26818    | 3.66895  | 0.0164   | 0.0268 | 0.1124 |
| 0.2499   | 0.2444     | 0.2400   | 0.2378   |        |        |
| 6        | 0.08331    | 6.58280  | 0.7072   | 0.0051 | 0.1810 |
| 0.3640   | 0.3637     | 0.3636   | 0.3632   |        |        |
| 7        | 0.03834    | 9.70339  | 0.2693   | 0.9637 | 0.7001 |
| 0.0059   | 0.0094     | 0.0124   | 0.0144   |        |        |

## G.6 Time-Series Based Dummy Variables

Using the combined time-series data set, I investigated the significance of the individual time series on the two dependant variables. I found that the significance of vessel horsepower remained the same for the two time-series, but that gross tonnage was more significant for the latter (1995-2000) time series.

Fig G-12: Time-Series Dummy Variables, Combined Panel Data

```

The SAS System
Model: MODEL1
Dependent Variable: INDEXDA

                                Analysis of Variance
                                Sum of      Mean
                                Squares     Square     F
Source      DF      Value      Prob>F
Model      4      498279192.51  124569798.13
330.624    0.0001
Error     700     263740261.47  376771.8021
C Total   704     762019453.97

                                Root MSE     R-square
0.6539
                                Dep Mean    Adj R-sq
0.6519
                                C.V.      37.51761

                                Parameter Estimates
                                Parameter     Standard     T for H0:
                                Estimate      Error
Parameter=0    Prob > |T|

```

|                          |            |          |             |             |
|--------------------------|------------|----------|-------------|-------------|
|                          | INTERCEP   | 1        | 231.120575  | 55.15283461 |
| 4.191                    |            | 0.0001   |             |             |
|                          | VHP        | 1        | 1.546612    | 0.31979942  |
| 4.836                    |            | 0.0001   |             |             |
|                          | GT         | 1        | 6.298576    | 1.36301854  |
| 4.621                    |            | 0.0001   |             |             |
|                          | VHPDUM95   | 1        | 0.313053    | 0.32725321  |
| 0.957                    |            | 0.3391   |             |             |
|                          | GTDUM95    | 1        | 6.391817    | 1.54001951  |
| 4.150                    |            | 0.0001   |             |             |
| Variance                 |            |          |             |             |
|                          | Variable   | DF       | Inflation   |             |
|                          | INTERCEP   | 1        | 0.00000000  |             |
|                          | VHP        | 1        | 6.91011091  |             |
|                          | GT         | 1        | 10.13155456 |             |
|                          | VHPDUM95   | 1        | 10.99539519 |             |
|                          | GTDUM95    | 1        | 11.25619587 |             |
| Collinearity Diagnostics |            |          |             |             |
|                          | Condition  | Var Prop | Var Prop    | Var         |
| Prop                     | Var Prop   | Var Prop | Var Prop    |             |
| Number                   | Eigenvalue | Index    | INTERCEP    | VHP         |
|                          | VHPDUM95   | GTDUM95  |             | GT          |
| 1                        | 4.11436    | 1.00000  | 0.0085      | 0.0014      |

|        |         |          |        |        |
|--------|---------|----------|--------|--------|
| 0.0018 | 0.0018  | 0.0024   |        |        |
| 2      | 0.48479 | 2.91323  | 0.0604 | 0.0059 |
| 0.0082 | 0.0175  | 0.0433   |        |        |
| 3      | 0.29763 | 3.71804  | 0.1270 | 0.0005 |
| 0.0575 | 0.0267  | 0.0214   |        |        |
| 4      | 0.09311 | 6.64749  | 0.7908 | 0.0888 |
| 0.0011 | 0.0520  | 0.0769   |        |        |
| 5      | 0.01011 | 20.17313 | 0.0133 | 0.9034 |
| 0.9314 | 0.9020  | 0.8561   |        |        |

**APPENDIX H: STANDARDIZING REVENUE**

All revenue data was standardized to 1993 dollars using a Bureau of Labor Statistics Producer Price Index for Finished Goods (Series WPSSOP3000). 1993 dollars was chosen rather randomly; no standard year emerged in the literature, and 1993, as the last year in the first time-series used, seemed appropriate.

Series WPSSOP3000 and the correction calculation results are included below.

Fig H-1: Bureau of Labor Statistics PPI for Finished Goods (Series WPSSOP3000)

| <b>Year</b> | <b>Jan</b> | <b>Feb</b> | <b>Mar</b> | <b>Apr</b> | <b>May</b> | <b>Jun</b> | <b>Jul</b> | <b>Aug</b> | <b>Sep</b> | <b>Oct</b> | <b>Nov</b> | <b>Dec</b> | <b>Annual</b> |
|-------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|---------------|
| <b>1989</b> | 111.1      | 111.9      | 112.3      | 113.1      | 114        | 114        | 113.8      | 113.4      | 114        | 114.6      | 114.8      | 115.5      | 113.54        |
| <b>1990</b> | 117.7      | 117.6      | 117.5      | 117.4      | 117.5      | 117.6      | 117.9      | 119.2      | 120.7      | 121.9      | 122.6      | 122        | 119.13        |
| <b>1991</b> | 122.6      | 121.8      | 121.3      | 121.3      | 121.6      | 121.4      | 121.1      | 121.3      | 121.5      | 121.9      | 122.4      | 122.3      | 121.71        |
| <b>1992</b> | 122        | 122.3      | 122.4      | 122.5      | 122.9      | 123.4      | 123.3      | 123.4      | 123.7      | 124.2      | 124.1      | 124.2      | 123.2         |
| <b>1993</b> | 124.4      | 124.7      | 125        | 125.7      | 125.7      | 125.2      | 125.1      | 123.9      | 124.1      | 124.2      | 124.4      | 124.4      | 124.73        |
| <b>1994</b> | 124.8      | 125        | 125.1      | 125.1      | 125.1      | 125.2      | 125.7      | 126.2      | 125.9      | 125.5      | 126.1      | 126.6      | 125.53        |
| <b>1995</b> | 126.9      | 127.2      | 127.4      | 127.7      | 127.8      | 127.8      | 128        | 127.9      | 128.1      | 128.4      | 128.7      | 129.3      | 127.93        |

|             |            |            |            |            |            |            |            |            |            |            |            |            |               |
|-------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|---------------|
| <b>1996</b> | 129.7      | 129.7      | 130.5      | 130.9      | 130.9      | 131.3      | 131.2      | 131.6      | 131.7      | 132.4      | 132.5      | 132.9      | 131.28        |
| <b>1997</b> | 133        | 132.6      | 132.6      | 131.8      | 131.4      | 131.3      | 131        | 131.5      | 131.7      | 131.9      | 131.6      | 131.3      | 131.81        |
| <b>1998</b> | 130.6      | 130.4      | 130.5      | 130.7      | 130.5      | 130.5      | 130.7      | 130.5      | 130.5      | 131        | 130.8      | 131.2      | 130.66        |
| <b>1999</b> | 131.7      | 131        | 131.5      | 132.2      | 132.3      | 132.4      | 132.7      | 133.6      | 134.5      | 134.6      | 134.7      | 135.2      | 133.03        |
| <b>2000</b> | 135.1      | 136.3      | 137.5      | 137.1      | 137.1      | 138.3      | 138.2      | 138        | 139        | 139.6      | 139.8      | 140        | 138           |
| <b>2001</b> | 141.6      | 141.7      | 141.6      | 142.3      | 142.4      | 141.9      | 140.2      | 140.7      | 141.4      | 139.1      | 138.3      | 137.4      | 140.72        |
|             |            |            |            |            |            |            |            |            |            |            |            |            |               |
| Std :       | 124.73     | 124.73     | 124.73     | 124.73     | 124.73     | 124.73     | 124.73     | 124.73     | 124.73     | 124.73     | 124.73     | 124.73     |               |
| Corr:       |            |            |            |            |            |            |            |            |            |            |            |            |               |
| <b>Year</b> | <b>Jan</b> | <b>Feb</b> | <b>Mar</b> | <b>Apr</b> | <b>May</b> | <b>Jun</b> | <b>Jul</b> | <b>Aug</b> | <b>Sep</b> | <b>Oct</b> | <b>Nov</b> | <b>Dec</b> | <b>Annual</b> |
| <b>1989</b> | 0.891      | 0.897      | 0.900      | 0.907      | 0.914      | 0.914      | 0.912      | 0.909      | 0.914      | 0.919      | 0.920      | 0.926      | <b>0.910</b>  |
| <b>1990</b> | 0.944      | 0.943      | 0.942      | 0.941      | 0.942      | 0.943      | 0.945      | 0.946      | 0.948      | 0.947      | 0.943      | 0.948      | <b>0.955</b>  |
| <b>1991</b> | 0.983      | 0.977      | 0.973      | 0.973      | 0.975      | 0.973      | 0.971      | 0.973      | 0.974      | 0.977      | 0.981      | 0.981      | <b>0.976</b>  |

|            |      |      |      |      |      |      |      |      |      |      |      |      |             |
|------------|------|------|------|------|------|------|------|------|------|------|------|------|-------------|
| <b>199</b> | 0.97 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.99 | 0.99 | 0.99 | 0.99 | <b>0.98</b> |
| <b>2</b>   | 8    | 1    | 1    | 2    | 5    | 9    | 9    | 9    | 2    | 6    | 5    | 6    | <b>8</b>    |
| <b>199</b> | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | <b>1.00</b> |
| <b>3</b>   | 7    | 0    | 2    | 8    | 8    | 4    | 3    | 3    | 5    | 6    | 7    | 7    | <b>0</b>    |
| <b>199</b> | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.01 | 1.00 | 1.00 | 1.01 | 1.01 | <b>1.00</b> |
| <b>4</b>   | 1    | 2    | 3    | 3    | 3    | 4    | 8    | 2    | 9    | 6    | 1    | 5    | <b>6</b>    |
| <b>199</b> | 1.01 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.03 | 1.03 | <b>1.02</b> |
| <b>5</b>   | 7    | 0    | 1    | 4    | 5    | 5    | 6    | 5    | 7    | 9    | 2    | 7    | <b>6</b>    |
| <b>199</b> | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.05 | 1.05 | 1.05 | 1.06 | 1.06 | 1.06 | <b>1.05</b> |
| <b>6</b>   | 0    | 0    | 6    | 9    | 9    | 3    | 2    | 5    | 6    | 1    | 2    | 6    | <b>2</b>    |
| <b>199</b> | 1.06 | 1.06 | 1.06 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | <b>1.05</b> |
| <b>7</b>   | 6    | 3    | 3    | 7    | 3    | 3    | 0    | 4    | 6    | 7    | 5    | 3    | <b>7</b>    |
| <b>199</b> | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.04 | 1.05 | <b>1.04</b> |
| <b>8</b>   | 7    | 5    | 6    | 8    | 6    | 6    | 8    | 6    | 6    | 0    | 9    | 2    | <b>8</b>    |
| <b>199</b> | 1.05 | 1.05 | 1.05 | 1.06 | 1.06 | 1.06 | 1.06 | 1.07 | 1.07 | 1.07 | 1.08 | 1.08 | <b>1.06</b> |
| <b>9</b>   | 6    | 0    | 4    | 0    | 1    | 1    | 4    | 1    | 8    | 9    | 0    | 4    | <b>7</b>    |
| <b>200</b> | 1.08 | 1.09 | 1.10 | 1.09 | 1.09 | 1.10 | 1.10 | 1.10 | 1.11 | 1.11 | 1.12 | 1.12 | <b>1.10</b> |
| <b>0</b>   | 3    | 3    | 2    | 9    | 9    | 9    | 8    | 6    | 4    | 9    | 1    | 2    | <b>6</b>    |
| <b>200</b> | 1.13 | 1.13 | 1.13 | 1.14 | 1.14 | 1.13 | 1.12 | 1.12 | 1.13 | 1.11 | 1.10 | 1.10 | <b>1.12</b> |
| <b>1</b>   | 5    | 6    | 5    | 1    | 2    | 8    | 4    | 8    | 4    | 5    | 9    | 2    | <b>8</b>    |

## APPENDIX I: COMPARISON OF MCP-BASED TRADES USING OLS AND SPF

### MODELED OUTPUT

A market-clearing price analysis of trades is performed using OLS estimations for modeled output. The results of this market were highly consistent with the results of the market based on SPF estimates for modeled output.

The following table compares the anticipated trades and changes in total fishery output between markets based on OLS and SPF estimations of output.

Table I-1: Summary of MCP-based trades using OLS and SPF estimations of output

|            | MCP    | Avg. Cost of<br>DAS per<br>Buyer | # Sellers | # Buyers | Mean SPF-Based<br>Residual Ratio of<br>Sellers | Mean SPF-Based<br>Residual Ratio of<br>Buyers | Predicted Increase in<br>Total Fishery Output<br>(%) |
|------------|--------|----------------------------------|-----------|----------|--|---|--|
| <b>SPF</b> | 0.4053 | \$1,143.98                       | 473       | 428      | 0.428355438                                    | 0.888449047                                   | 129.8  |
| <b>OLS</b> | 0.5875 | \$1,122.69                       | 466       | 435      | 0.421694944                                    | 0.888180392                                   | 118.7  |

Two paired t-tests are performed on the OLS and SPF-based output markets. First test compares the predicted average cost of a DAS for individual buyers under the two markets. The second test compares the predicted annual output of individual buyers under the two markets. The results indicate that there is very little difference between the two markets.

Fig I-1: Paired t-test, predicted average cost of a DAS for buyers under SPF and OLS output-based markets

```
. ttest OLS_Cost = SPF_Cost
```

| Variable | Obs | Mean | Std. Dev. |
|----------|-----|------|-----------|
|----------|-----|------|-----------|

```

-----+-----
OLS_Cost |      463      1052.119      618.3329
SPF_Cost |      463      1054.769      529.689
-----+-----
diff. |      463      -2.650063      382.5874

```

Ho: mean difference = 0 (paired data)

t = -0.15 with 462 d.f.

Pr > |t| = 0.8816

95% CI for difference = (-37.590463,32.290337)

Fig I-2: Paired t-test, predicted annual output of buyers under SPF and OLS output-based markets

```
. ttest OLS_Out = SPF_Out

Variable |      Obs      Mean   Std. Dev.
-----+-----
OLS_Out |      463  399085.8  214942.6
SPF_Out |      463  405019.5  216322.9
-----+-----
diff.   |      463  -5933.743  100136.2

Ho: mean difference = 0 (paired data)
t = -1.28 with 462 d.f.
Pr > |t| = 0.2029
95% CI for difference = (-15078.833,3211.3466)
```

## APPENDIX J: MARKET DATA SET

To create the data set for analyzing trades, cross-sectional data from the 1995-2000 time-series are used. The 1100 vessels from this data set are merged with NMFS DAS allocation records, leaving 921 vessels<sup>40</sup>. Vessels issued “combination permits<sup>41</sup>” that are allocated less than 88 DAS per year are eliminated because it is impossible to predict their potential as buyers or sellers. 902 vessels remain in this data set. The data set has the following characteristics:

Table J-1: Descriptive summary of market data set

|                                  |                    |
|----------------------------------|--------------------|
| <b>Number of Vessels</b>         | <b>902</b>         |
| <b>Mean Days Absent/Year</b>     | <b>45.7</b>        |
| Std Dev                          | 37.3               |
| Max                              | 179.0              |
| Min                              | 5.0                |
| <b>Mean DAS Allocated</b>        | <b>94.6</b>        |
| Std Dev                          | 16.3               |
| Max                              | 181                |
| Min                              | 88                 |
| <b>Mean Observed Revenue/Day</b> | <b>\$ 1,641.59</b> |
| <b>(\$)</b>                      |                    |
| Std Dev                          | \$ 1,118.95        |

<sup>40</sup> 179 vessels had documented landings during the 1995-2000 time-series but were not found in the current (2001) DAS allocation database. Some of these vessels are likely to have retired from the fishery or transferred their permit to another vessel; others may be subject to permit sanctions and therefore have no DAS issued for 2001. I cannot confirm that these two explanations account for all 179 vessels.

<sup>41</sup> Combination permits allow vessels to fish for both scallops and groundfish. 45 vessels had such permits issued as of 2000, and only 23 of these vessels utilized any portion of their groundfish DAS (NMFS 2001).

|                                      |              |
|--------------------------------------|--------------|
| Max                                  | \$ 9,054.11  |
| Min                                  | \$ 95.10     |
| <b>Mean Horsepower (hp)</b>          | <b>389.2</b> |
| Std Dev                              | 197.7        |
| Max                                  | 2000         |
| Min                                  | 54           |
| <b>Mean Gross Tonnage (tons)</b>     | <b>55.2</b>  |
| Std Dev                              | 51.4         |
| Max                                  | 258          |
| Min                                  | 4            |
| <b>Mean SPF-based Residual Ratio</b> | <b>0.65</b>  |
| Std Dev                              | 0.30         |
| Max                                  | 2.49         |
| Min                                  | 0.06         |

## Appendix K: DAS Utilization-Based Sellers and Buyers

### K.0 Introduction

At the point where quality-adjusted DAS demanded (by buyers) and quality-adjusted DAS supplied (by sellers) are equal, several possibilities for buyer and seller DAS utilization rates exist. Consequently it is impossible to summarize characteristics of vessels predicted to be sellers and buyers for every permutation. Instead, one permutation was selected and summarized for sellers and buyers.

### K.1 Sellers

This sample data sub-set includes all vessels with an observed DAS utilization rate of less than 28% of their historical allocation (defined as sellers).

Table K-1: Summary of predicted sellers based on DAS utilization (< 28%)

|   |                    |
|---|--------------------|
| <b>Number of Vessels</b>                  | <b>351</b>         |
| <b>Mean Days Absent/Year</b>              | <b>13.5</b>        |
| Std Dev                                   | 5.5                |
| Max                                       | 27.6               |
| Min                                       | 5.0                |
| <b>Mean DAS Allocated</b>                 | <b>89.8</b>        |
| Std Dev                                   | 8.6                |
| Max                                       | 181                |
| Min                                       | 88                 |
| <b>Mean Observed Revenue/Day<br/>(\$)</b> | <b>\$ 1,216.03</b> |
| Std Dev                                   | \$ 1,006.63        |
| Max                                       | \$ 9,054.11        |
| Min                                       | \$ 95.10           |
| <b>Mean Horsepower (hp)</b>               | <b>354.7</b>       |
| Std Dev                                   | 188.8              |
| Max                                       | 1380               |
| Min                                       | 120                |
| <b>Mean Gross Tonnage (tons)</b>          | <b>41.1</b>        |
| Std Dev                                   | 46.1               |
| Max                                       | 258                |
| Min                                       | 4                  |
| <b>Mean SPF-based Residual</b>            | <b>0.53</b>        |

|              |      |
|--------------|------|
| <b>Ratio</b> |      |
| Std Dev      | 0.29 |
| Max          | 2.03 |
| Min          | 0.06 |

## K.2 Buyers

This sample data sub-set includes all vessels with an observed DAS utilization rate of greater than 75% of their historical allocation (defined as buyers).

Table K-2: Summary of predicted buyers based on DAS utilization (>75)

|   |                    |
|---|--------------------|
| <b>Number of Vessels</b>                  | <b>349</b>         |
| <b>Mean Days Absent/Year</b>              | <b>84.5</b>        |
| Std Dev                                   | 30.4               |
| Max                                       | 179.0              |
| Min                                       | 45.0               |
| <b>Mean DAS Allocated</b>                 | <b>101.4</b>       |
| Std Dev                                   | 21.4               |
| Max                                       | 164                |
| Min                                       | 88                 |
| <b>Mean Observed Revenue/Day<br/>(\$)</b> | <b>\$ 2,045.93</b> |
| Std Dev                                   | \$ 1,164.14        |
| Max                                       | \$ 7,382.14        |
| Min                                       | \$ 372.31          |
| <b>Mean Horsepower (hp)</b>               | <b>421.7</b>       |
| Std Dev                                   | 206.7              |
| Max                                       | 2000               |
| Min                                       | 110                |
| <b>Mean Gross Tonnage (tons)</b>          | <b>70.2</b>        |
| Std Dev                                   | 54.2               |
| Max                                       | 199                |
| Min                                       | 5                  |
| <b>Mean SPF-based Residual</b>            | <b>0.74</b>        |

| <b>Ratio</b> |      |
|--------------|------|
| Std Dev      | 0.28 |
| Max          | 2.49 |
| Min          | 0.13 |

### K.3 Results of Potential Trades

Below is a summary of anticipated results at each market-clearing permutation based on historical DAS utilization.

Table K-3: Summary of trades at various DAS utilization rates

| Residual<br>Ratio-Seller<br>(<) | Residual<br>Ratio-Buyer<br>(>) | # Sellers | # Buyers | Mean<br>Residual Ratio-<br>Sellers | Mean<br>Residual Ratio-<br>Buyers | Anticipated Increase<br>in Fishery Total<br>Output | Change in<br>Net DAS<br>Allocated |
|---------------------------------|--------------------------------|-----------|----------|------------------------------------|-----------------------------------|--|-----------------------------------|
| 0.35                            | 0.39                           | 423       | 426      | 0.55394                            | 0.73105                           | 83.52%   | -4.44%                            |
| 0.34                            | 0.4                            | 412       | 420      | 0.54957                            | 0.73110                           | 82.67%   | -3.87%                            |
| 0.33                            | 0.43                           | 401       | 403      | 0.54978                            | 0.73176                           | 77.63%   | -4.48%                            |
| 0.32                            | 0.44                           | 389       | 395      | 0.54822                            | 0.73138                           | 76.24%   | -3.96%                            |
| 0.31                            | 0.45                           | 376       | 384      | 0.54158                            | 0.73152                           | 72.83%   | -3.74%                            |
| 0.3                             | 0.47                           | 368       | 374      | 0.53804                            | 0.73388                           | 70.94%   | -3.96%                            |
| 0.29                            | 0.49                           | 360       | 360      | 0.53686                            | 0.73506                           | 68.13%   | -4.58%                            |
| 0.28                            | 0.51                           | 351       | 349      | 0.52959                            | 0.73989                           | 66.29%   | -4.78%                            |
| 0.27                            | 0.52                           | 345       | 341      | 0.52806                            | 0.74094                           | 65.29%   | 52.00%                            |
| 0.26                            | 0.54                           | 331       | 326      | 0.52609                            | 0.73566                           | 60.24%   | -5.17%                            |
| 0.25                            | 0.55                           | 326       | 323      | 0.52562                            | 0.73587                           | 59.50%   | -4.98%                            |
| 0.24                            | 0.58                           | 309       | 310      | 0.52667                            | 0.73629                           | 56.97%   | -4.56%                            |
| 0.23                            | 0.61                           | 296       | 292      | 0.51976                            | 0.74259                           | 53.90%   | -5.15%                            |
| 0.22                            | 0.62                           | 287       | 287      | 0.51925                            | 0.74383                           | 52.70%   | -4.71%                            |
| 0.21                            | 0.65                           | 273       | 271      | 0.51559                            | 0.75526                           | 50.21%   | -4.93%                            |
| 0.2                             | 0.66                           | 263       | 263      | 0.51353                            | 0.75185                           | 48.60%   | -4.76%                            |
| 0.19                            | 0.68                           | 255       | 248      | 0.51489                            | 0.75577                           | 45.62%   | -5.49%                            |
| 0.18                            | 0.72                           | 232       | 228      | 0.51410                            | 0.75940                           | 41.85%   | -4.96%                            |
| 0.17                            | 0.74                           | 221       | 215      | 0.51022                            | 0.75726                           | 38.79%   | -4.99%                            |
| 0.16                            | 0.75                           | 207       | 207      | 0.51553                            | 0.75923                           | 37.22%   | -4.27%                            |
| 0.15                            | 0.78                           | 188       | 188      | 0.51662                            | 0.76664                           | 33.45%   | -3.97%                            |
| 0.14                            | 0.83                           | 163       | 163      | 0.50628                            | 0.76799                           | 28.06%   | -3.48%                            |
| 0.13                            | 0.87                           | 144       | 143      | 0.49804                            | 0.78537                           | 24.37%   | -3.32%                            |
| 0.12                            | 0.89                           | 128       | 129      | 0.49514                            | 0.79662                           | 21.84%   | -2.98%                            |
| 0.11                            | 0.91                           | 116       | 120      | 0.48273                            | 0.79641                           | 19.94%   | -2.33%                            |
| 0.1                             | 0.94                           | 95        | 99       | 0.48339                            | 0.80975                           | 16.19%   | -2.09%                            |
| 0.09                            | 0.97                           | 73        | 81       | 0.49790                            | 0.79201                           | 12.06%   | -1.18%                            |

## Appendix L: SPF Residual Ratio-Based Sellers and Buyers

### L.0 Introduction

At the point where quality-adjusted DAS demanded (by buyers) and quality-adjusted DAS supplied (by sellers) are equal, several possibilities for buyer and seller DAS utilization rates exist. One permutation was selected and characteristics of vessels predicted to be buyers and sellers are summarized below.

### L.1 Sellers

This sample data sub-set includes all vessels with SPF residual ratios of less than 0.45 (defined as sellers).

Table L-1: Summary of predicted sellers based on SPF residual ratio (>0.45)

|   |                 |
|---|-----------------|
| <b>Number of Vessels</b>                  | <b>246</b>      |
| <b>Mean Days Absent/Year</b>              | <b>27.4</b>     |
| Std Dev                                   | 24.2            |
| Max                                       | 112.9           |
| Min                                       | 5.1             |
| <b>Mean DAS Allocated</b>                 | <b>88.7</b>     |
| Std Dev                                   | 5.6             |
| Max                                       | 157             |
| Min                                       | 88              |
| <b>Mean Observed Revenue/Day<br/>(\$)</b> | <b>\$649.62</b> |
| Std Dev                                   | \$ 319.58       |
| Max                                       | \$ 1,841.35     |
| Min                                       | \$ 95.10        |
| <b>Mean Horsepower (hp)</b>               | <b>348.2</b>    |
| Std Dev                                   | 199.6           |
| Max                                       | 2000            |
| Min                                       | 120             |
| <b>Mean Gross Tonnage (tons)</b>          | <b>32.0</b>     |
| Std Dev                                   | 31.8            |
| Max                                       | 171             |
| Min                                       | 4               |
| <b>Mean SPF-based Residual</b>            | <b>0.31</b>     |

|              |      |
|--------------|------|
| <b>Ratio</b> |      |
| Std Dev      | 0.10 |
| Max          | 0.45 |
| Min          | 0.06 |

## L.2 Buyers

This sample data sub-set includes all vessels with SPF residual ratios of greater than 0.82 (defined as buyers).

Table L-2: Summary of predicted buyers based on SPF residual ratio (>0.82)

|                                       |                    |
|---------------------------------------|--------------------|
| <b>Number of Vessels</b>              | <b>230</b>         |
| <b>Mean Days Absent/Year</b>          | <b>59.5</b>        |
| Std Dev                               | 41.2               |
| Max                                   | 165.7              |
| Min                                   | 5                  |
| <b>Mean DAS Allocated</b>             | <b>99.8</b>        |
| Std Dev                               | 20.9               |
| Max                                   | 181                |
| Min                                   | 88                 |
| <b>Mean Observed Revenue/Day (\$)</b> | <b>\$ 2,698.01</b> |
| Std Dev                               | \$ 1,206.25        |
| Max                                   | \$ 9054.11         |
| Min                                   | \$ 959.87          |
| <b>Mean Horsepower (hp)</b>           | <b>417.0</b>       |
| Std Dev                               | 196.7              |
| Max                                   | 1380               |
| Min                                   | 54                 |
| <b>Mean Gross Tonnage (tons)</b>      | <b>63.6</b>        |
| Std Dev                               | 54.2               |
| Max                                   | 201                |
| Min                                   | 4                  |
| <b>Mean SPF-based Residual Ratio</b>  | <b>1.04</b>        |
| Std Dev                               | 0.24               |

|     |      |
|-----|------|
| Max | 2.49 |
| Min | 0.82 |

### L.3 Results of Potential Trades

Below is a summary of anticipated results at each market-clearing permutation based SPF residual ratio.

Table L-3: Summary of trades at various residual ratios

| Residual<br>Ratio-Seller<br>(<) | Residual<br>Ratio-Buyer<br>(>) | # Sellers | # Buyers | Mean Residual<br>Ratio-Sellers | Mean Residual<br>Ratio-Buyers | Anticipated Increase<br>in Fishery Total<br>Output (%) | Change in Net<br>DAS Allocated<br>(%) |
|---------------------------------|--------------------------------|-----------|----------|--------------------------------|-------------------------------|--|---------------------------------------|
| 0.6                             | 0.65                           | 424       | 410      | 0.40240                        | 0.90448                       | 115.89%  | -53.45%                               |
| 0.59                            | 0.66                           | 411       | 401      | 0.39630                        | 0.91013                       | 115.09%  | -51.88%                               |
| 0.58                            | 0.67                           | 400       | 386      | 0.39114                        | 0.91964                       | 112.92%  | -50.41%                               |
| 0.57                            | 0.68                           | 390       | 374      | 0.38643                        | 0.92750                       | 110.46%  | -49.25%                               |
| 0.56                            | 0.7                            | 371       | 351      | 0.37734                        | 0.94302                       | 106.34%  | -46.40%                               |
| 0.55                            | 0.71                           | 360       | 339      | 0.37195                        | 0.95142                       | 102.40%  | -45.04%                               |
| 0.54                            | 0.72                           | 351       | 333      | 0.36749                        | 0.95565                       | 103.10%  | -44.07%                               |
| 0.53                            | 0.73                           | 335       | 322      | 0.35948                        | 0.96351                       | 96.77%   | -41.79%                               |
| 0.52                            | 0.74                           | 326       | 310      | 0.35488                        | 0.97233                       | 97.14%   | -40.86%                               |
| 0.51                            | 0.75                           | 315       | 299      | 0.34933                        | 0.98069                       | 94.46%   | -39.38%                               |
| 0.5                             | 0.76                           | 301       | 283      | 0.34207                        | 0.99345                       | 90.31%   | -37.65%                               |
| 0.49                            | 0.77                           | 288       | 274      | 0.33562                        | 1.00096                       | 88.03%   | -37.34%                               |
| 0.48                            | 0.78                           | 274       | 265      | 0.32851                        | 1.00859                       | 85.86%   | -35.86%                               |
| 0.47                            | 0.79                           | 265       | 254      | 0.32392                        | 1.01831                       | 83.06%   | -34.13%                               |
| 0.46                            | 0.8                            | 265       | 245      | 0.32392                        | 1.02649                       | 81.53%   | -32.67%                               |
| 0.45                            | 0.82                           | 246       | 230      | 0.31381                        | 1.04045                       | 78.22%   | -30.64%                               |
| 0.44                            | 0.83                           | 236       | 223      | 0.30828                        | 1.04722                       | 73.57%   | -29.13%                               |
| 0.43                            | 0.84                           | 227       | 215      | 0.30324                        | 1.05513                       | 70.31%   | -28.08%                               |
| 0.42                            | 0.85                           | 213       | 205      | 0.29528                        | 1.06529                       | 68.41%   | -26.35%                               |
| 0.41                            | 0.86                           | 202       | 197      | 0.28873                        | 1.07384                       | 65.96%   | -25.21%                               |
| 0.4                             | 0.87                           | 194       | 191      | 0.28394                        | 1.08038                       | 63.35%   | -24.02%                               |
| 0.39                            | 0.88                           | 185       | 182      | 0.27852                        | 1.09050                       | 60.38%   | -22.81%                               |
| 0.38                            | 0.89                           | 172       | 171      | 0.27047                        | 1.10367                       | 58.38%   | -21.44%                               |
| 0.37                            | 0.91                           | 160       | 156      | 0.26261                        | 1.12314                       | 54.36%   | -19.45%                               |
| 0.36                            | 0.92                           | 153       | 149      | 0.25786                        | 1.13299                       | 51.80%   | -18.49%                               |
| 0.35                            | 0.93                           | 140       | 142      | 0.24895                        | 1.14323                       | 49.60%   | -16.95%                               |
| 0.34                            | 0.95                           | 127       | 129      | 0.23908                        | 1.16381                       | 45.34%   | -15.53%                               |
| 0.33                            | 0.96                           | 118       | 122      | 0.23181                        | 1.17576                       | 42.82%   | -14.56%                               |
| 0.32                            | 0.98                           | 110       | 106      | 0.22500                        | 1.20704                       | 40.09%   | -13.55%                               |
| 0.31                            | 0.98                           | 107       | 106      | 0.22245                        | 1.20704                       | 38.80%   | -13.06%                               |
| 0.3                             | 0.99                           | 99        | 100      | 0.21583                        | 1.22042                       | 36.40%   | -11.93%                               |

Appendix M: Market-Clearing Price-Based Sellers and Buyers

M.0 Sellers

This sample data sub-set includes all vessels with negative per-day profits when there is not net excess supply or demand for quality-adjusted DAS.

Table M-1: Summary of predicted sellers at MCP = 0.4053

|   |                 |
|---|-----------------|
| <b>Number of Vessels</b>                  | <b>473</b>      |
| <b>Mean Days Absent/Year</b>              | <b>32.4</b>     |
| Std Dev                                   | 26.1            |
| Max                                       | 125.1           |
| Min                                       | 5.1             |
| <b>Mean DAS Allocated</b>                 | <b>89.3</b>     |
| Std Dev                                   | 7.3             |
| Max                                       | 157             |
| Min                                       | 88              |
| <b>Mean Observed Revenue/Day<br/>(\$)</b> | <b>\$922.46</b> |
| Std Dev                                   | \$ 541.17       |
| Max                                       | \$ 4,081.40     |
| Min                                       | \$ 95.10        |
| <b>Mean Horsepower (hp)</b>               | <b>352.3</b>    |
| Std Dev                                   | 199.0           |
| Max                                       | 2000            |

|                                      |             |
|--------------------------------------|-------------|
| Min                                  | 110         |
| <b>Mean Gross Tonnage (tons)</b>     | <b>37.1</b> |
| Std Dev                              | 40.2        |
| Max                                  | 258         |
| Min                                  | 4           |
| <b>Mean SPF-based Residual Ratio</b> | <b>0.43</b> |
| Std Dev                              | 0.15        |
| Max                                  | 0.72        |
| Min                                  | 0.06        |

#### M.1 Buyers

This sample data sub-set includes all vessels with positive profits per day at the equilibrium MCP.

Table M-2: Summary of predicted buyers at MCP = 0.4053

|                              |              |
|------------------------------|--------------|
| <b>Number of Vessels</b>     | <b>428</b>   |
| <b>Mean Days Absent/Year</b> | <b>60.4</b>  |
| Std Dev                      | 42.1         |
| Max                          | 179.0        |
| Min                          | 5            |
| <b>Mean DAS Allocated</b>    | <b>100.2</b> |
| Std Dev                      | 20.6         |
| Max                          | 164          |

|  |                    |
|--|--------------------|
| Min  | 88                 |
| <b>Mean Observed Revenue/Day</b><br>(\$)       | <b>\$ 2,434.11</b> |
| Std Dev  | \$ 1,055.35        |
| Max  | \$ 9054.11         |
| Min  | \$ 875.21          |
| <b>Mean Horsepower (hp)</b>                    | <b>429.6</b>       |
| Std Dev  | 188.2              |
| Max  | 1380               |
| Min  | 54                 |
| <b>Mean Gross Tonnage (tons)</b>               | <b>75.3</b>        |
| Std Dev  | 55.0               |
| Max  | 201                |
| Min  | 4                  |
| <b>Mean SPF-based Residual</b><br><b>Ratio</b> | <b>0.89</b>        |
| Std Dev  | 0.25               |
| Max  | 2.49               |
| Min  | 0.53               |

## M.2 Results of Potential Trades

Below is a summary of anticipated results at each combination of profit/loss threshold and MCP.

Table M-3: Summary of trades predicted by the MCP at various profit/loss thresholds

| Profit/Loss<br>Threshold | MCP      | Avg. Price<br>Paid per |           | #      |         | Mean<br>Residual Ratio |         | Anticipated Increase<br>in Fishery Total<br>Output | Change in<br>Net DAS<br>Allocated |
|--------------------------|----------|------------------------|-----------|--------|---------|------------------------|---------|--|-----------------------------------|
|                          |          | DAS                    | # Sellers | Buyers | Sellers | Ratio-Buyers           |         |  |                                   |
| \$50                     | \$0.4143 | \$1,172.88             | 462       | 418    | 0.42290 | 0.89406                | 118.58% | -11.81%  |                                   |
| \$100                    | \$0.4235 | \$1,204.32             | 453       | 409    | 0.41865 | 0.89902                | 115.73% | -13.71%  |                                   |
| \$150                    | \$0.4355 | \$1,237.79             | 437       | 399    | 0.41089 | 0.90549                | 111.92% | -15.82%  |                                   |
| \$200                    | \$0.4455 | \$1,267.22             | 422       | 385    | 0.40367 | 0.91342                | 106.40% | -18.77%  |                                   |
| \$250                    | \$0.4561 | \$1,300.11             | 409       | 374    | 0.39724 | 0.92020                | 102.29% | -21.09%  |                                   |
| \$300                    | \$0.4678 | \$1,331.08             | 393       | 362    | 0.39029 | 0.92889                | 97.38%  | -23.62%  |                                   |
| \$350                    | \$0.4810 | \$1,371.02             | 375       | 351    | 0.38157 | 0.93611                | 93.12%  | -25.95%  |                                   |
| \$400                    | \$0.4933 | \$1,407.67             | 360       | 339    | 0.37607 | 0.94474                | 88.36%  | -28.48%  |                                   |
| \$450                    | \$0.5029 | \$1,438.86             | 339       | 324    | 0.36826 | 0.95486                | 82.20%  | -31.64%  |                                   |
| \$500                    | \$0.5179 | \$1,481.60             | 324       | 312    | 0.36107 | 0.96326                | 77.00%  | -34.17%  |                                   |
| \$550                    | \$0.5285 | \$1,518.57             | 307       | 302    | 0.35452 | 0.97024                | 73.09%  | -36.28%  |                                   |
| \$600                    | \$0.5414 | \$1,558.71             | 294       | 291    | 0.34945 | 0.97835                | 68.36%  | -38.60%  |                                   |
| \$650                    | \$0.5526 | \$1,580.81             | 282       | 282    | 0.34515 | 0.98547                | 63.46%  | -40.50%  |                                   |
| \$700                    | \$0.5609 | \$1,603.50             | 268       | 272    | 0.34012 | 0.99394                | 58.90%  | -42.61%  |                                   |
| \$750                    | \$0.5702 | \$1,620.59             | 252       | 263    | 0.33572 | 1.00269                | 54.17%  | -44.51%  |                                   |

## Appendix N: Trade Predictions in a Market Excluding Latent DAS

To assess the impact of DAS shifting towards efficient operators, a sample market is created that excludes historically unused DAS. Vessels predicted to be sellers based on the DAS utilization, residual ratio and MCP criteria are assumed to sell a total number of DAS equal to their average DAS use from 1995-2000. Latent DAS are thereby removed from the market.

The following table summarizes anticipated trades based on this market. For the change in net DAS allocated column in this table, allocations are assumed to be active-use DAS only. For the MCP criteria, the profit/loss threshold is set at zero.

Table N-1: Summary of trades excluding latent DAS

| Method                 | Market Clearing Equilibrium | Avg. Price Paid per DAS | # Sellers | # Buyers | Mean Residual Ratio of Sellers | Mean Residual Ratio of Buyers | Predicted Increase in Total Fishery Output (%) | Change in Net DAS Allocated (%) |
|------------------------|-----------------------------|-------------------------|-----------|----------|--------------------------------|-------------------------------|--|---------------------------------|
| <b>DAS Utilization</b> | 0.28/1.00                   | N/A                     | 251       | 66       | 0.52959                        | 0.78010                       | 3.03   | -31.20                          |
| <b>Residual Ratio</b>  | 0.45/1.12                   | N/A                     | 246       | 54       | 0.31381                        | 1.37424                       | 18.20  | -23.70                          |
| <b>MCP</b>             | 0.6069                      | \$1,706                 | 676       | 226      | 0.51695                        | 1.03647                       | 36.00  | -1.30                           |

The predicted increase in total fishery output is between 50% and 75% less than the increase predicted by the markets when latent DAS are included. This provides further evidence that, while the shift in DAS from less to more efficient vessels has a pronounced impact, it is likely that the introduction of previously latent DAS accounts for a far larger increase in total fishery output.

## Appendix O: Impact of Total Fleet DAS Reductions on MCP-Based Trade Predictions

Decreasing the DAS allocation of all vessels by a uniform percentage has been the preferred method of reducing effort in the groundfish fleet. To assess the impact of overall DAS reductions, a market was created where individual DAS allocations were reduced by various percentages. Trades are predicted using the MCP criteria with no profit/loss threshold (i.e. all vessels are either buyers or sellers). The artificial cap on individual DAS allocations remains set at 180 DAS.

The following table summarizes potential trades at various DAS allocation reductions.

Table O-1: Summary of trades at varying DAS reduction levels

| Overall DAS Reduction | MCP           | Avg. Price Paid per DAS | # Sellers  | # Buyers   | Mean Residual Ratio of Sellers | Mean Residual Ratio of Buyers | Predicted Increase in Total Fishery Output | Change in Net DAS Allocated |
|-----------------------|---------------|-------------------------|------------|------------|--------------------------------|-------------------------------|--|-----------------------------|
| 10%                   | 0.4489        | \$1,273.13              | 519        | 383        | 0.44925                        | 0.91524                       | 105.76%                                    | -19.19%                     |
| 15%                   | 0.4699        | \$1,334.56              | 540        | 362        | 0.45813                        | 0.92903                       | 97.61%                                     | -23.62%                     |
| 20%                   | 0.4934        | \$1,405.19              | 563        | 339        | 0.46781                        | 0.94489                       | 88.60%                                     | -28.48%                     |
| 25%                   | 0.5121        | \$1,459.43              | 585        | 317        | 0.47760                        | 0.95994                       | 79.22%                                     | -33.12%                     |
| 30%                   | 0.5379        | \$1,539.51              | 608        | 294        | 0.48775                        | 0.97669                       | 69.54%                                     | -37.97%                     |
| 35%                   | 0.5598        | \$1,596.93              | 627        | 275        | 0.49602                        | 0.99161                       | 60.54%                                     | -41.98%                     |
| 40%                   | 0.5788        | \$1,645.17              | 647        | 255        | 0.50459                        | 1.00875                       | 50.91%                                     | -46.20%                     |
| <b>45%</b>            | <b>0.5943</b> | <b>\$1,669.50</b>       | <b>666</b> | <b>236</b> | <b>0.51227</b>                 | <b>1.02765</b>                | <b>40.81%</b>                              | <b>-50.21%</b>              |
| 50%                   | 0.6169        | \$1,732.68              | 687        | 215        | 0.52197                        | 1.04700                       | 30.56%                                     | -54.64%                     |
| 55%                   | 0.6358        | \$1,772.94              | 707        | 195        | 0.53085                        | 1.06864                       | 20.09%                                     | -58.86%                     |
| 60%                   | 0.6621        | \$1,832.25              | 728        | 174        | 0.54138                        | 1.08951                       | 8.48%                                      | -63.29%                     |
| 65%                   | 0.7012        | \$1,931.84              | 749        | 153        | 0.55130                        | 1.11618                       | -2.71%                                     | -67.72%                     |
| 70%                   | 0.7272        | \$2,006.33              | 771        | 131        | 0.56259                        | 1.14457                       | -14.60%                                    | -72.36%                     |

It is important to note that, because all vessels in this scenario are either buyers or sellers, and because all sellers are assumed to sell their entire allocation of DAS (and hence exit the fishery), the “# Buyers” column also represents the final predicted size of the groundfish fishing fleet.

The “45%” overall DAS reduction row, in bold face, is the overall reduction in DAS that corresponds to the point where the predicted DAS utilized is equal to the total amount of DAS utilized observed prior to market trades. The interesting observation here is that, for the same level of nominal effort, roughly 40% more output is predicted to be produced (and by one-third the number of vessels). This rather tentatively indicates that the amount of increase in output attributable to shifts in efficiency as a result of DAS trades is on the order of 40%.

## Appendix P: MCP-Based Trade Predictions With No Latent DAS Traded

The anticipated increase in total fishery output has two root causes: the shift of DAS from efficient to inefficient operators, and the introduction of previously unused DAS into the fishery. To assess the impact of DAS shifting towards efficient operators only, a sample market is created that excludes previously unused DAS.

All vessels with historical DAS utilization rates less than 88% are excluded, leaving 121 vessels in the data set for this sample market. The following table summarized anticipated trades and predicted increase in total fishery output based on this market.

Table P-1: Summary of MCP-based trades by vessels with historical DAS utilization > 0.88

| MCP   | # Sellers | # Buyers | Mean Residual Ratio of Sellers | Mean Residual Ratio of Buyers | Predicted Increase in Total Fishery Output (%) | Change in Net DAS Allocated (%) |
|-------|-----------|----------|--------------------------------|-------------------------------|--|---------------------------------|
| 0.514 | 49        | 72       | 0.52732                        | 0.97281                       | 14.30%   | 0.31%                           |

The characteristics of vessels involved in this sample market differ significantly from those of the fleet as a whole. The following table summarizes these differences.

Table P-2: Comparison of vessel characteristics between market data set and a sub-set of this market restricted to vessels with historical DAS utilization > 0.88

|                     | # vessels | Mean VHP | Mean GT | Mean Daily Output |
|---------------------|-----------|----------|---------|-------------------|
| Complete Data Set   | 902       | 203.42   | 55.2    | 1641.6            |
| Restricted Data Set | 121       | 462.31   | 82.0    | 2386.15           |

Table P-3: Comparison of residual ratios for buyer and sellers between market data set and a sub-set of this market restricted to vessels with historical DAS utilization > 0.88

|                     | Mean Residual Ratio of Sellers | Mean Residual Ratio of Buyers |
|---------------------|--------------------------------|-------------------------------|
| Complete Data Set   | 0.42290                        | 0.89406                       |
| Restricted Data Set | 0.52732                        | 0.97281                       |

While the subset of vessels with few historically latent DAS includes larger, more powerful vessels, the differential between buyer/seller residual ratios for the unrestricted and restricted markets is within 10%. We can therefore make very general comparisons between the unrestricted market and its restricted counterpart based on the elimination of latent DAS.

The net change in total output as a result of this restricted market lends further credence to the conclusion that increases in output due to changes in fleet efficiency are significant, but not as significant as increases due to the overall DAS utilization of the fleet.

**APPENDIX Q: IMPACT OF A CONSERVATION MULTIPLIER ON MCP-BASED TRADE PREDICTIONS**

ONE POSSIBLE METHOD OF REDUCING THE PREDICTED INCREASE IN TOTAL FISHERY OUTPUT IS TO IMPOSE A MULTIPLIER ON EACH TRADE. TO ASSESS THE IMPACT OF SUCH A “CONSERVATION MULTIPLIER,” THE SAME MARKET IS ANALYZED WITH A CONSERVATION FACTOR ( $\phi$ ) DESIGNED TO INCREASE “ $\alpha$ ” FOR ALL BUYERS SUCH THAT BUYERS PURCHASE QUALITY-ADJUSTED DAS AT A HIGHER RATE THAN SELLERS SELL THEM. THE IMPACT OF THIS CONSERVATION FACTOR CAN BE REPRESENTED MATHEMATICALLY:

(Q-1)  $\alpha_B = E_I * Y_I * \phi$

WHERE:

$\alpha_B$  = QUANTITY OF QUALITY-ADJUSTED DAS PURCHASED BY BUYERS, AND

$\phi$  = CONSERVATION MULTIPLIER

THE FOLLOWING TABLE SUMMARIZES POTENTIAL TRADES AT VARIOUS LEVELS OF “ $\phi$ .”

TABLE Q-1: SUMMARY OF TRADES AT VARYING LEVELS OF “ $\phi$ ”

| Con-<br>servation<br>Factor | MCP           | Avg. Price<br>Paid per<br>DAS | #<br>Sellers | #<br>Buyers | Mean Residual<br>Ratio of Sellers | Mean Residual<br>Ratio of Buyers | Predicted Increase<br>in Total Fishery<br>Output (%) | Change in Net<br>DAS Allocated<br>(%) |
|-----------------------------|---------------|-------------------------------|--------------|-------------|-----------------------------------|----------------------------------|--|---------------------------------------|
| 1                           | 0.4053        | \$1,143.98                    | 473          | 428         | 0.42836                           | 0.88845                          | 129.80%  | -9.70%                                |
| 2                           | 0.5325        | \$3,056.11                    | 606          | 295         | 0.48694                           | 0.97554                          | 69.80%   | -37.80%                               |
| <b>3</b>                    | <b>0.5961</b> | <b>\$5,025.00</b>             | <b>668</b>   | <b>234</b>  | <b>0.51323</b>                    | <b>1.02931</b>                   | <b>39.90%</b>  | <b>-50.60%</b>                        |
| 4                           | 0.6398        | \$7,098.77                    | 711          | 191         | 0.53279                           | 1.07268                          | 17.50%   | -59.70%                               |
| 5                           | 0.671         | \$9,223.88                    | 736          | 166         | 0.54482                           | 1.10069                          | 3.90%  | -65.00%                               |

BECAUSE ALL VESSELS IN THIS SCENARIO ARE EITHER BUYERS OR SELLERS, AND ALL SELLERS ARE ASSUMED TO SELL THEIR ENTIRE ALLOCATION OF DAS (EXITING THE FISHERY), THE “# BUYERS” COLUMN ALSO REPRESENTS THE FINAL PREDICTED SIZE OF THE GROUND FISH FISHING FLEET.

Conservation multiplier “3” is in bold face, as this represents the point where the number of DAS utilized is predicted to be equal to the total amount of DAS utilized observed prior to market trades. Similar to Appendix O, the point where nominal effort after trading equals nominal effort before trading yields roughly 40% greater output from the fishery. This further strengthens the concept that shifting DAS from less to more efficient operator’s accounts for 40% of the net increase in predicted output observed in the predictions.

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