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Pooled and Individual Bycatch Quotas: Exploring Tradeoffs Between Observer Coverage Levels, Bycatch Frequency, Pool Size, and the Precision of Bycatch Estimates

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ABSTRACT

The North Pacific Ocean is highly productive, hosting many of the world's largest groundfish populations and supporting a thriving fishing industry. Numerous regulations have been implemented to control the incidental take of non-target bycatch. Individual and Pooled Bycatch Quotas have recently been proposed as instruments that could further encourage the avoidance of such bycatch and increase enforceability of bycatch caps at less-than-entire-fishery levels of operation. The recent advent of fishing cooperatives such as the Pacific Whiting Conservation Cooperative and the Pollock Conservation Cooperatives create an additional impetus for examining the characteristics of pool and vessel specific bycatch quotas.

We have constructed an object-oriented, hierarchical simulation that allows us to aggregate hauls of individual fish, up to single vessels, vessel pools, fleets (pools of vessel pools), and the entire fishery. This simulator is written in the object-oriented programming language, Java. It provides the flexibility to examine various sampling techniques and strategies and allows us to follow the precision of incidental catch estimates at various levels of operation. In particular, we examine the tradeoffs between the precision of bycatch estimates and consider management costs as observer coverage and pool size are varied.

POOLED AND INDIVUDAL BYCATCH QUOTAS: EXPLORING TRADEOFFS BETWEEN OBSERVER COVERAGE LEVELS, BYCATCH FREQUENCY, POOL SIZE, AND THE PRECISION OF BYCATCH ESTIMATES[1]

Introduction

Bycatch arises from the use of harvesting technologies that imperfectly discriminate between target and non-target fish stocks. Even with a homogenous fishing fleet and without significant biological interactions, joint harvesting of multiple species poses problems for managers. For example, consider a fishery where two stocks are harvested in fixed proportions. Because population parameters vary across species, it is unlikely that optimal exploitation of one stock would simultaneously result in optimal catches of the other. To achieve optimal catches of the first stock, it would probably be necessary to accept suboptimal (low or high) harvests of the second. When fishers differ in their preferences for the two species, managers must trade-off benefits to the first sector against losses to the second. Similar problems arise even when there are no technological interactions if there are direct or indirect trophic interactions. Actual fisheries include both types of interaction. Consequently, it is difficult to predict the ecological or bioeconomic consequences of changes in target and incidental catch limits.

Although elimination of bycatch may be uneconomical or even infeasible, the volume and composition of bycatch can be controlled indirectly through characteristics of the harvest gear, towing depth and speed, as well the time, season, and location fished. That is, bycatch is in part avoidable. For example, vessels operating during the CDQ (Community Development Quota) pollock (*Theragra chalcogramma*) fishery attain higher product recovery rates and lower bycatch rates than they attain while participating in the open access fishery that immediately precedes the CDQ opening. Similarly high recovery rates and reduced incidental catches have been reported for vessels participating in the pollock cooperative.

Bycatch may include marketable as well as non-marketable species or sizes. Some bycatch is retained and marketed. Other bycatch is discarded at sea or after delivery to a processing facility. There are many reasons for the discard of incidental catches. Some bycatch is discarded as a result of regulatory requirements. For example, the BSAI (Bering Sea and Aleutian Islands) and GOA (Gulf of Alaska) FMPs (Fishery Management Plans) mandate the discard of salmon (*Oncorhynchus spp.*), king crab (*Paralithodes spp.*), Tanner crab (*Chionoecetes bairdi*), snow crab (*C. opilio*) and herring (*Clupea pallasi*). The amended FMPs also require the discard of halibut (*Hippoglossus stenolepis*) and sablefish (*Anoplopoma fimbria*) unless the vessel owner/operator has unfished IFQ (Individual Fishing Quota), or in the case of halibut, when the vessel is using other than longline gear. These discards are required to prevent surreptitious targeting. In addition, discards are typically required when the bycatch species TAC (Total Allowable Catch) has been exceeded and are mandated when the species' ABC (Acceptable Biological Catch) has been exceeded.

Discard of target and incidental catch also occurs for fiscal reasons. For example, when the exvessel price is less than the opportunity cost of retention. Some incidental catch has no market, so the exvessel price is

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zero. (It could actually be negative if the "purchaser" must incur costs to dispose of the unmarketable incidental catch.) Additional fish are discarded to conserve hold space for higher valued target species. For example, although the halibut fishery encounters significant bycatches of rockfish (*Sebastes* spp. and *Sebastalobus* spp.), and although most of these rockfish and thornyheads command high exvessel prices, most of this bycatch was discarded during the derby fishery because the special handling that they require would have detracted from effort focused on handling halibut catches. This latter form of fiscal discard is exacerbated by the race for fish and can be controlled through direct prohibition, as has been done for incidental catches of cod (*Gadus macrocephalus*) and pollock in amendments to the BSAI and GOA FMPs (NPFMC, 1996), or through elimination of the race for fish.

Because bycatch limits on prohibited species, especially halibut, have led to numerous fishery closures and the overall under exploitation of some stocks (Witherell and Pautzke, 1997), the North Pacific Fishery Management Council and various industry groups have explored management options and collective actions intended to offset the common property characteristics of bycatch caps. Among the measures that have been implemented or discussed are Vessel Incentive Programs for red king crab, halibut, and salmon, moral suasion through posting of vessel specific bycatch rates, the Alaska Marine Conservation Council harvest priority proposal, and various voluntary avoidance programs (e.g., Gauvin, Haflinger and Nerini, 1996).

IBQs (Individual Bycatch Quotas), also known as VBAs (Vessel Bycatch Allocations), have been proposed as an instrument that could reduce the common property dilemma and lead to the avoidance of prohibited species bycatches. By avoiding bycatch, fishers can increase their opportunity to harvest the target species when other fishers are shutdown. Overall bycatch can be reduced by reducing the IBQ pool. IBQ programs could follow design principles employed in tradable emissions quotas (Tietenberg, 1985) or lobster trap certificates (SAFMC/GFMC, 1992), with a portion of the quota shares attenuating over time as a means of reducing bycatch to a lower target. Transferability encourages high-bycatch fishers to exit the fishery.

The MSFCMA (Magnuson-Stevens Fishery Conservation and Management Act of 1996) includes provisions to encourage the avoidance of or retention and utilization of bycatch. In addition, the Act permits the development of IBQs. Section 303(a)(11) of the Act stipulates:

> "Any fishery management plan which is prepared by any Council, or by the Secretary, with respect to any Fishery shall—... establish a standardized reporting methodology to assess the amount and type of bycatch occurring in the fishery, and include conservation and management measures that, to the extent practicable and in the following priority—(A) minimize bycatch; and (B) minimize the mortality of bycatch which cannot be avoided; ..."

Section 313(f) notes:

> "In implementing section 303(a)(11) and this section, the North Pacific Council shall submit conservation and management measures to lower, on an annual basis for a period of not less than four years, the total amount of economic discards occurring in the fisheries under its jurisdiction.

Section 313(g)(2) adds:

> (A) Notwithstanding section 303(d)[2], and in addition to the authority provided in section 303(b)(10)[3], the North Pacific Council may submit, and the Secretary may approve, conservation and management measures which provide allocations of regulatory discards to individual vessels as an incentive to reduce per vessel bycatch and bycatch rates in a fishery, *Provided*, That—(i) such allocations may not be transferred for monetary consideration and

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[2] Section 303(d) places a moratorium on the development of individual fishing quotas for target species.

[3] Section 303(b)(10) authorizes incentives for fishers to employ practices that reduce bycatch or bycatch mortality.

are made only on an annual basis; and (ii) any such conservation and management measures will meet the requirements of subsection (h) and will result in an actual reduction in regulatory discards in the fishery.

(B) The North Pacific Council may submit restrictions in addition to the restriction imposed by clause (i) of subparagraph (A) on the transferability of any such allocations, and the Secretary may approve such recommendation.

Section 313(h) mandates the development of accurate measures of catch and bycatch:

(1) By June 1, 1997 the North Pacific Council shall submit, and the Secretary may approve, consistent with other provisions of this Act, conservation and management measures to ensure total catch measurement in each fishery under the jurisdiction of such Council. Such measures shall ensure the accurate enumeration, at a minimum, of target species, economic discards, and regulatory discards.

Furthermore, a recently completed National Research Council report (NRC, 1999) finds that

"Although individual bycatch quotas have not yet been developed by regional fishery management councils, they may be a useful tool for controlling the magnitude of bycatch and through individual accountability, encouraging fishermen to avoid bycatch".

The report recommends that:

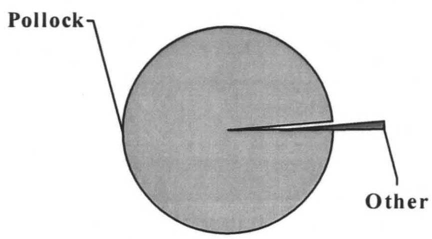
"The Councils should be encouraged to explore the use of individual and pooled bycatch quotas to control overall bycatch and to give fishermen the incentive to minimize their bycatch rates."

A second motivation for this analysis is provided by implementation considerations of the American Fisheries Act (1998). Among other measures, the Act provides authorization and financial inducements for the formation of fishery cooperatives. The possible apportionment of prohibited species bycatch caps among and within these cooperatives could, in the limit, is equivalent to an IBQ.

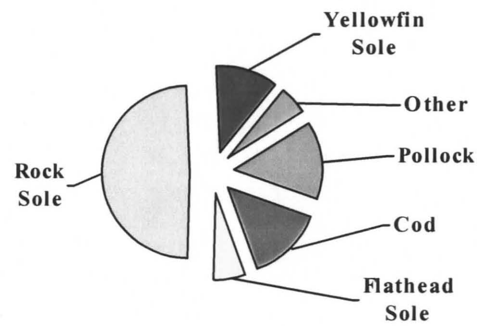
Effective implementation of IBQs requires an accurate accounting of incidental catches. Several factors contribute to the accurate accounting of incidental catches. Onboard observer/sampling programs prevent catches from being "sanitized". Sampling variances are influenced by the sampling strategy, the fraction of the catch sampled, and the incidence of bycatch. Low frequency bycatches have higher sampling variances and larger confidence intervals for a given number of samples. If the confidence intervals are large, only egregious overages are prosecutable. Assigning bycatch quota to vessel pools could narrow the confidence intervals on estimates of bycatch, increasing enforceability.

Bycatch and bycatch minimization have been the subject of numerous studies and workshops (e.g., Smith 1993, Alverson et al. 1994, Queirolo et al. 1995, Alaska Sea Grant 1996 and 1997). Recent examinations of the bycatch in the fisheries off Alaska have focused on operational aspects of the North Pacific Fisheries Observer program. These studies have dealt with issues such as sampling protocols, estimate expansion, and the statistical properties of estimates (e.g., Dorn et al. 1997, Volstad et al. 1997, Pennington 1996, and Pennington and Volstad 1994). Physical and practical constraints limit the frequency and randomness of sampling, affecting the variance and bias of sample estimates. Pooling observations across hauls, vessels, regions, and time, reduces variance but has an indeterminate effect on bias. While there is consensus that fleet-wide estimates of bycatch are sufficiently precise to preclude overfishing of bycatch species, experience with the Vessel Incentive Program (salmon bycatch reduction) suggests vessel-level estimates of bycatch may not satisfy evidentiary standards. One approach to this conundrum would be to increase tow-by-tow sample frequency, through employing additional observers. An alternative approach is to pool estimates across subsets of the fleet. These alternatives involve tradeoffs in cost to implement, estimate precision, and individual accountability.

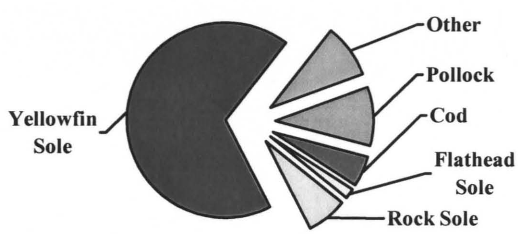
The primary objective of this project is to develop an economic framework for exploring the costs of achieving various levels of precision as a function of observer coverage and vessel-pool size. The model will be applied to the pollock (*Theragra chalcogramma*) midwater trawl, and the yellowfin sole (*Limanda aspera*) and rock sole (*Lepidopsetta bilineata*) bottom trawl fisheries. These fisheries exhibit substantially different bycatch rates.



Pollock Midwater Trawl (1,042,300 mt)

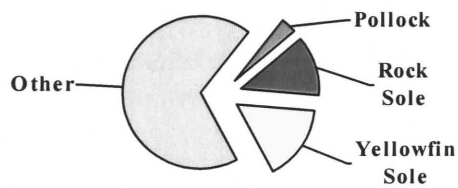


Rock Sole Bottom Trawl (64,500 mt)

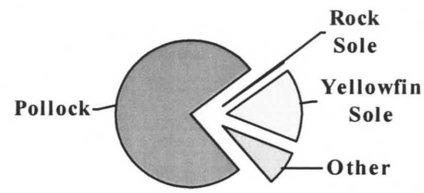


Yellowfin Sole Bottom Trawl (249,500 mt)

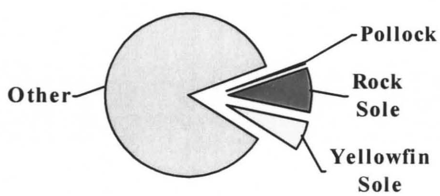
Figure 1.—Target and incidental catches for three Bering Sea fisheries in 1997: the pollock midwater trawl, and the rock sole and yellowfin sole bottom trawl fisheries.



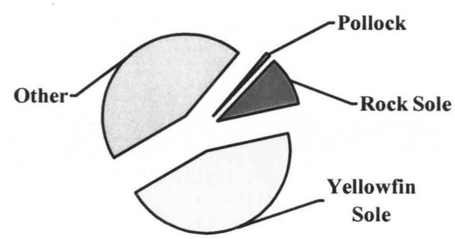
Halibut Bycatch (4,668.6 mt)



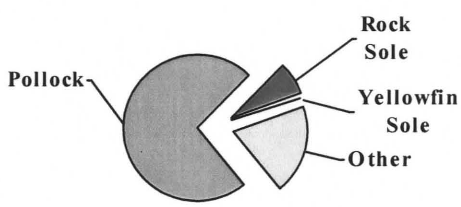
Herring Bycatch (1,512.6 mt)



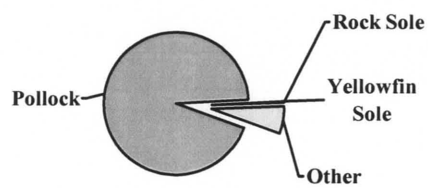
King Crab Bycatch (126,600 crab)



Snow and Tanner Crab Bycatch (6,026,000 crab)



Chinook Salmon Bycatch (63,200 fish)



Other Salmon Bycatch (78,100 fish)

Figure 2.—Prohibited species bycatch for three Bering Sea fisheries in 1997: the pollock midwater trawl, and the rock sole and yellowfin sole bottom trawl fisheries.

The North Pacific Ocean is highly productive, hosting many of the world's largest groundfish populations and supporting a major fishing industry. With the passage of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1976, the U.S. declared exclusive management authority over all fish resources in the Exclusive Economic Zone. Subsequently, fishery management plans for the Bering Sea and Aleutian Islands (BSAI) groundfish fisheries have been addressed by the North Pacific Fishery Management Council (NPFMC) in order to locate the correct balance between many economic and ecological issues. One continuing aim and goal of fishery managers remains the problem of minimizing bycatch, especially that concerned with prohibited species bycatch (PSC), while attaining optimum yield of target groundfish species.

Numerous regulations have been implemented to control the incidental take of prohibited bycatch species, including species such as halibut, herring, salmon, and crab, in eastern Bering Sea groundfish fisheries. Some of these regulatory measures have included bycatch limits, gear restrictions, area and season closures, and bycatch rate standards, along with provisions for monitoring and enforcement.

Individual and Pooled Bycatch Quotas (IBQs) have been proposed as instruments that could further encourage the avoidance of incidental catches. By avoiding bycatch, wise fishermen could remain under quota levels and continue fishing for a particular target species when other fishermen with filled quotas are forced to shutdown. Overall bycatch could be reduced by reducing the IBQ pool and a potential program could follow design principles similar to those employed in tradable emissions quotas, with a portion of the quota shares attenuating over time as a means of reducing bycatch to a lower target.

With the advent of the recently enacted American Fisheries Act (AFA) of 1998, the proposition of IBQs has drawn more attention. A critical aspect of the Act contains provisions for the creation of pollock cooperatives that have pooled bycatch quotas. The advent of these offshore pollock coops and the potential formation of the shore-based coops will soon bring fishery managers up against many issues related to the management and enforcement of bycatch caps at increasingly smaller scales of operation. These AFA coops would create IBQs for coop members using contracts and relying on civil law to enforce contract terms, including penalties for excessive bycatches.

Specific research is needed to assess the feasibility and potential advantages of setting up an IBQ program. Effective implementation of such a program would require an accurate accounting of incidental catches. Current onboard observer sampling programs report valuable catch data while preventing catches from being presorted and sanitized. Several factors effect the accounting of incidental catches, including sampling strategy, observer coverage, and the incidence of bycatch. If the variances of bycatch estimates are large, only obvious bycatch overages are prosecutable. By assigning bycatch quotas to vessel pools or coops, we hope to increase precision of bycatch estimates, providing more effective management and enforcement tools for the fishing industry.

The aim of this research is to address specific policy questions concerning the bycatch problem encountered within the Alaska fishing industry. Numerous regulations have been implemented to control the incidental take of non-target bycatch with varied success. The potential formation of fishery coops bring fishery managers up against issues related to the enforcement of bycatch caps at increasingly smaller scales of operation. IBQs have been proposed as instruments that could create real incentives for fishermen to avoid incidental bycatch and produce more efficient fishing practices.

The MSFCMA (Magnuson-Stevens Fishery Conservation and Management Act of 1996) includes a provision to encourage the avoidance of bycatch, and in addition permits the development of IBQs. Furthermore, a recently completed National Research Council report (NRC, 1999) finds that

"Although individual bycatch quotas have not yet been developed by regional fishery management councils, they may be a useful tool for controlling the magnitude of bycatch and through individual accountability, encouraging fishermen to avoid bycatch".

The report also recommends that

"The Councils should be encouraged to explore the use of individual and pooled bycatch quotas to control overall bycatch and to give fishermen the incentive to minimize their bycatch rates".

Effective implementation of IBQs requires an accurate accounting of incidental catches, and further research is needed to illuminated the tradeoffs between estimate precision, observer coverage parameters, pool size, and bycatch frequency.

The primary objective of this project consists in building a hierarchical, object-oriented, Java simulator based on the actual fishing and observer sampling processes. Our simulator allows us to aggregate hauls of individual fish, up to single vessels, vessel pools, fleets (pools of vessel pools), and up to the entire fishery. Our simulator provides the flexibility to examine various sampling techniques and strategies and allows us to follow the precision of incidental catch estimates at various levels of fishing operation.

This simulator will be used to explore the relationships and tradeoffs between observer coverage, pool size, bycatch frequency, and the estimated precision for bycatch species encountered in the Bering Sea trawl fisheries. We examine the pollock midwater trawl and the yellowfin sole bottom trawl fisheries, which exhibit substantially different bycatch rates. Our final goal is to produce a simulator framework that can be used to achieve various levels of bycatch estimate precision as a function of observer coverage and pool size. It is hoped this research will guide and inform policy decisions involved in the structuring, monitoring, and enforcement of fishery coops and pooled bycatch quotas.

The tasks involved in this project can be divided into the following algorithm, with in-depth details described in subsequent chapters and appendices:

Collection and analysis of actual observer data used to parameterize our simulations.

In Section 2, we describe the queries used to search appropriate information and create useful data sets from the NORPAC Database. We then discuss the methods used to read and analyze these enormous data files and provide details on present and possible future implementations of this information into our simulator. Finally, we consider methods to determine the vessel costs necessary for achieving various levels of precision as a function of the observer coverage parameters.

Development of the theoretical and modeling framework, where simulations will be performed.

In Section 3, we discuss how the advantages of Java programming can be applied to our simulator. We also describe the hierarchy of objects and Java class files involved in our simulations, and detail their functionality and implementation. In Section 4, we detail how multistage cluster sampling will be implemented in our simulator and provide discussion on the use of the coefficient of variation as a practical measure of estimate precision.

Multiple simulations used to examine the relationship between estimate precision and the choice variables.

In Section 5, we outline the steps required for running elementary simulations. Multiple simulations are run to obtain Monte-Carlo variance estimates used to calculate bycatch estimate precision. Simulation results are investigated graphically and we discuss possible implementation in coop formation and enforcement methods. In Section 6, we discuss practical and potential uses for our simulator and possible extensions on our existing framework.

Data Resources

During an internship at the Alaska Fisheries Science Center, a data sharing agreement with NMFS was signed and authorized to allow us access to tow-by-tow information for the 1997 pollock midwater trawl and yellowfin sole bottom trawl fisheries. The goal was to build real data sets of tow-by-tow (haul-by-haul) observer information and make them accessible in a form for use in the final simulator. The confidential information concerning specific vessel identification is not used in any form in performing simulations.

We are able to query and compile data from the NORPAC Database, as collected by the North Pacific Groundfish Observer Program, using the information provided in the NORPAC.DOMESTIC_HAUL and NORPAC.DOMESTIC_SPCOMP tables.

It should be noted that NMFS uses a blend of observer data and data from processor production in the development of official information used for management. By concentrating on the observer data alone, we have avoided inclusion of the weekly processor report data with its poorly characterized error structure.

After collecting huge amounts of information, with one data file containing over 40,000 unique observations of over 50 variables, it became important to find an efficient method of sorting through the data to isolate specific pieces of information. At the moment, we are most interested in the information concerned with total catch weight and catch weight species-by-species, as can be found in the variables norpac.domestic_haul.official_tons and norpac.domestic_spcomp.species_haul_wt respectively. From these variables we can easily calculate the proportion of the total catch weight for each species, which will be used to characterize target and bycatch species frequency.

It was quickly found that many statistical packages, such as Splus, ran into memory problems while sifting through the massive amounts of data collected. This motivated us to write Java programs utilizing the powerful class of StringTokenizers to efficiently tackle the problem and arrange the data into a form more adapted for our simulator.

We are able to isolate data on the total catch weight and target species (e.g., pollock or yellowfin sole) proportion of the total catch. Using the Splus script provided, or any statistical software package, we can obtain empirical histograms of their distributions. We see that hauls taken in the pollock midwater trawl fishery are relatively large and pure, while those collected in the yellowfin sole bottom trawl fishery are smaller and more mixed.

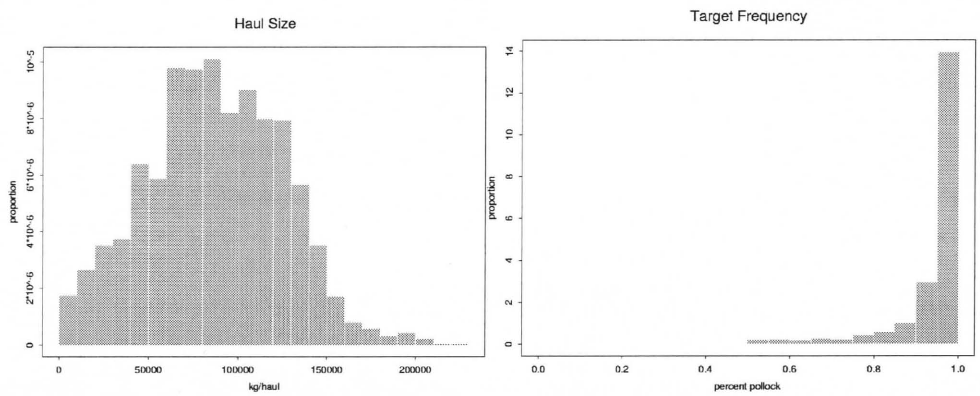


Figure 3.—Empirical histograms obtained for total catch weight (left) and porportion of pollock in total catch (right), obtained from the pollock midwater trawl fishery.

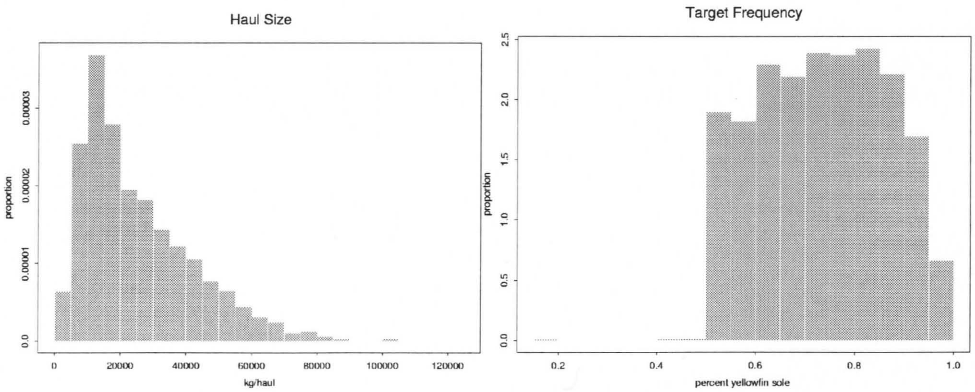


Figure 4.—Empirical histograms obtained for total catch weight (left) and proportion of yellowfin sole in total catch (right), obtained from the yellowfin sole bottow trawl fishery.

From these skewed distributions, we calculate median statistics as a measure of central tendency, and use these as fixed parameter values for maximum haul size and target species proportion in our simulations from each fishery as outlined in the following table.

Table 1 Fixed parameter values for maximum haul size and target species frequency as used in final simulations.

SIMUATION PARAMETERS	PARAMETER VALUE
Pollock: Maximum Haul Size	86.920 (mt)
Pollock: Frequency of Target Species	0.9758561
Yellowfin Sole: Maximum Haul Size	20.570 (mt)
Yellowfin Sole: Frequency of Target Species	0.7352938

Model Parameters

Under the model framework, discussed in detail in Section 3, we aim to explore the relationship between the variance of bycatch estimates given the situation prescribed by a few choice variables. These choice variables include the pool size (number of vessels pooled together) and observer coverage parameters, which include both the fraction of hauls observed and the proportion of each haul sampled. The distribution or frequency of bycatch also plays a significant part in determining estimate precision, and we aim to model situations of relatively clean fishing as seen in the pollock midwater trawl fishery, as opposed to a more mixed fishery as found in the yellowfin sole bottom trawl fishery.

The observer sampling costs for an individual vessel depend explicitly on the observer coverage parameters. For a fixed pool size, increasing observer coverage results in more precise estimates but also in increased sampling costs. Observer coverage can be increased by either increasing the fraction of hauls observed or the proportion of each haul sampled.

From this we argue that relative sampling costs, or an appropriate measure of observer sampling costs per haul fished per metric ton of catch, are directly proportional to observer coverage. In turn, observer coverage is directly proportional to both the fraction of hauls observed and the proportion of each haul sampled. Therefore, our relative sampling costs are also directly proportional to both the fraction of hauls observed and the proportion of each haul sampled,

$$Cost \propto (FractionOfHaulsObserved) \times (FractionOfHaulSampled).$$

We might consider combining the observer coverage variables by multiplying them together into an overall observer coverage metric. This would serve to simplify development of a cost functional associated with individual vessel fishing within a specific pool. Thus, depending on the number of hauls brought onboard and their corresponding total catch sizes, we could convert our observer coverage metric into actual dollars.

For example, a single observer onboard an individual vessel observing 30 percent of the total hauls brought aboard and sampling 50 percent of each haul observed, corresponds to an observer coverage level of 0.054. If the observer remains on board for 100 total hauls, each of size 20 metric tons, and samples at a rate of 5 metric tons per hour at $10.00 an hour will cost the fishing vessel $600.00 in sampling costs. Furthermore, a pool of 5 such vessel situations would correspond to $3,000.00 in overall sampling costs.

Model Framework

Much time and effort have gone into coding the Java class files associated with the hierarchical structure of our fishing and sampling simulator. We have implemented a multi-thread, platform independent, runtime environment that mimics the realistic situation of numerous vessels simultaneously fishing independent from each other. Our object-oriented approach also offers flexibility that should accommodate strategic changes in fishery structures associated with AFA and possible changes in the properties of bycatch estimates that could arise when observer sampling protocols are revised.

The simulator can be broken into two separate types of objects: simulator objects and data/information objects, which are described in detail below.

A graphical hierarchy of the simulator objects can be seen in the diagram below. Working from bottom to top, individual fish make up a specific sample collected from a specific haul. These are hauls are taken from an individual vessels in a particular pool and fleet, fishing in a specific fishery. Each object is described in detail below.

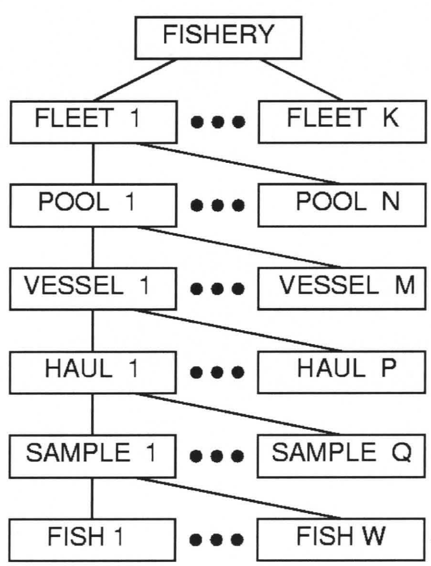


Figure 5.—Heirarachy of Fishing Simulator Objects

The most basic building block in the fishing process is comprised of the individual fish or FishObjects. Each object of this type contains the specific information (e.g., weight) on a unique fish that has been caught or is being sampled. For example, if in a simulation a vessel catches 500 pollock in a haul there will be 500 unique objects of type FishObject representing individual pollock, each with distinct weight. This allows the simulator to obtain exact catch totals on all species that can then be compared with various estimates.

The HaulObject contains a collection of individual fish, or FishObjects, as caught by a fishing vessel. Exact information on the total weight and species-by-species weights for an individual haul are updated continuously, fish-by-fish, during the fishing process. Once a haul has started, it continues to bring in fish, according to a specific fishing method as detailed in Section 5, until either the vessel's fishing net has reached its maximum capacity or it receives an order from its vessel to quit fishing and bring in that haul. For example, if in a simulation, a vessel brings in 10 hauls there will be 10 objects of type HaulObject representing unique hauls. The exact total weight and species-by-species weights for each haul are relayed back up to the vessel containing that haul.

Each HaulObject has a companion SampleObject that contains information from that haul as would be collected by an on-board observer. Thus by implementing a given specific sampling protocol as detailed in Section 5, our SampleObject contains some portion of the total information in a HaulObject and we can obtain estimates for the total weight and species-by-species weights for each haul that has been selected to be observed. The estimates for each observed haul are also relayed back up to the vessel level.

The VesselObject contains the information specific to an individual vessel. This includes unique name and identification information; along with specific vessel characteristics of vessel size, maximum hold capacity, and maximum haul size (e.g., net capacity). Such information is considered confidential but the model could potentially be used by NMFS to monitor and track specific vessels within a fishery.

Exact and estimated values for total weight and species-by-species weights are collected by HaulObjects and associated SampleObjects. These values are updated continuously during the fishing process, and are further reported to the pool containing that vessel. Once a vessel begins fishing, it continues to bring in hauls, according to a specified fishing and sampling scheme, until either the vessel hold fills to capacity and it must wait for processing or it receives an order from a hypothetical pool manager to quit fishing.

For simplification purposes, we assume an observer remains aboard at all times, and samples some fixed proportion of random hauls according to some specific sampling strategy. However, the situation of not having an observer onboard will be functionally equivalent to having an observer onboard sampling zero percent of the hauls.

A collection of vessels creates a PoolObject, and collects the aggregate exact and estimated values of total weight and species-by-species weights as reported by the various vessels. Again, these values are updated continuously during the fishing process. It also contains unique name and identification information and a specified catch limit or quota for each target or bycatch species. These catch limits are where we implement the use of Pooled Bycatch Quotas. Thus once a pool has started fishing, its vessels continue fishing until either the pooled bycatch quota is exceeded for any given species or it receives an order from a hypothetical fleet manager to quit fishing. This creates the possibility for some pools within a fleet to remain fishing while others exceed their catch quotas and are forced to shutdown.

A FleetObject is a simple collection of PoolObjects, and again contains the aggregate exact and estimated values for total weight and species-by-species weights as reported by the various pools. Again, these values are updated continuously during the fishing process. Once a fleet has started fishing, its pools continue fishing until either each pool exceeds their bycatch quota and is shutdown or the fleet receives an order from a hypothetical fishery manager to quit fishing.

Finally, the FisheryObject is a simple collection of FleetObjects, and again contains the aggregate exact and estimated values for total weight and species-by-species weights as collected by the various fleets within the specific fishery. These values are updated continuously during the fishing process. Once a fishery has started fishing, its fleets continue fishing until either each fleet is eventually shutdown or it receives an order to quit fishing.

Apart from the framework of runnable objects used to run and implement our simulations, we have an object that is specifically designated to store data on a particular fish species. While this object is used in our simulator, it provides only implicit functionality, and contains no substantial method calls.

The SpeciesObject contains the specific information for a single species of fish that might possibly be taken in the fishing process. The information includes name and identification information along with various biological characteristics, including average values of weight, length, and density, with corresponding standard deviations. Each object contains a distribution from which we may draw random individuals in our simulations as described below, and whether it is regarded as a target, bycatch, or prohibited species. When a FishObject is created in the simulator, the specific details (e.g., weight) of the individual fish are obtained by referencing the appropriate SpeciesObject.

Sampling and Precision

The North Pacific Groundfish Observer Program is a key component in providing effective management and enforcement. The sampling protocols and measurements collected by the observer program are described in the "Manual for Biologists Aboard Domestic Groundfish Vessels" (AFSC, 1999). The general instructions ask that observers collect random, unbiased samples from the catches so that data represent the vessel catches over time. This information is used to report independent estimates of catch weight and determines species composition of catches. With the possible situation of large vessels bringing on enormous catches at all hours of the day, a practical multi-stage sampling strategy is implemented.

A multi-stage random sample is constructed by taking a series of simple random samples in stages. This type of sampling is often more practical than simple random sampling for situations requiring "on location" analysis, such as door-to-door surveys. In a multistage random sample, a large area, such as a country, is first divided into smaller regions (such as states), and a random sample of these regions is collected. In the second stage, a random sample of smaller areas (such as counties) is taken from within each of the regions chosen in the first stage. Then, in the third stage, a random sample of even smaller areas (such as neighborhoods) is taken from within each of the areas chosen in the second stage. If these areas are sufficiently small for the purposes of the study, then the researcher might stop at the third stage. If not, he or she may continue to sample from the areas chosen in the third stage, etc., until appropriately small areas have been chosen.

In the current Observer Program, sampling from a certain fleet generally involved three stages of selection: (1) selection of vessels (primary sampling units); (2) selection of hauls (secondary sampling units) from each vessel; and (3) subsampling of the catches from each selected haul. The third stage of selection involves the use of whole-haul sampling, partial haul sampling, or basket sampling to determine the composition of the catch. The overall variance in estimates of fleetwide total catch and bycatch rates can be broken into three components, corresponding to the three sampling stages described above.

We assume that simple random sampling, without replacement, is employed in the first, second, and third stages when sampling for catch by species. This implies that the observers are deployed on a random sample of vessels from a fleet. First-stage sampling in the pollock midwater trawl fishery is 100% of vessels, where 100% coverage applies to all large vessels in the Gulf of Alaska and Bering Sea. Each observer collects catch data from a random sample of hauls from each of these vessels. We further assume that the species composition subsampling of hauls produce perfect, or at least unbiased, estimates of composition for each catch. Species compositions from partial haul samples are expanded to the entire catch of that haul. Hence, the estimation of total catch and bycatch values can be characterized by a two-stage cluster sampling design.

The subsequent table summarizes the notation used in the estimation of catch and bycatch values. The method is general, and can be used for fleets with less that 100% sampling coverage of fishing days.

Table 2 Notation used in general two-stage cluster sampling

POPULATION (FLEET)	SAMPLE	DEFINED AS
N	n	# of vessels
M_i	m_i	# of tows for vessel i; $i = 1,2,\ldots,n$ (sample)
X_{ij}	x_{ij}	Weight of a species of interest for haul j, $j = 1,2,\ldots m_i$
Y_{ij}	y_{ij}	Total weight of haul j, $j = 1,2,\ldots m_i$

Use of multistage cluster sampling is essential to understand how estimates of the sampled hauls are combined to produce vessel estimates, how estimates of observed vessels are combined to produce pool estimates, and so forth up the hierarchy of fishing objects until we obtain estimates at the fishery level.

Unbiased Estimators

We employ standard statistical techniques to calculate estimators for the multi-stage cluster-sampling scheme described above. For example, a pool estimator for total catch of a specific species would be

$$\hat{X}_{..} = \frac{N}{n}\sum_{i=1}^{n} M_i \bar{x}_{i.}$$

where an estimate of the mean catch per haul of that species for vessel i is given by

$$\bar{x}_{i.} = \frac{1}{m_i}\sum_{j=1}^{m_i} x_{ij} \ .$$

Following the notation in Wolter (1985), the subscript ".." signifies that the estimate is based on units selected in two stages, while the subscripts i denotes that the estimate applies to the ith unit, based on observations from the m_i second stage units.

These unbiased estimates are explicitly implemented in the getSample() method contained in our SampleObject code, and are subsequently present in the methods used to update estimates at the vessel level, pool level, fleet level, and fishery level.

To verify proper implementation of this unbiased estimation scheme, we use our SampleObject main method to repeat simulations of creating a haul and processing a sample from that haul to obtain exact and estimated values for bycatch weight. We used the repeated simulations to collect a sample using the difference between the exact and estimated bycatch weight and use Splus to create histograms such as the one shown below. The histogram appears symmetric about 0 and thus our estimator appears to indeed be unbiased. Similarly, simulation estimates at remaining levels of fishing operation can be shown have unbiased properties.

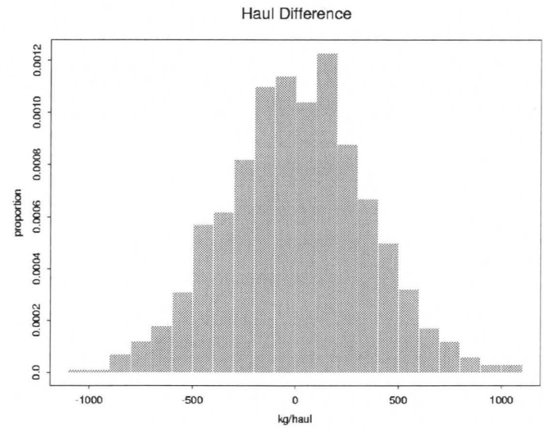


Figure 6.—Histogram of the difference between exact and estimated weights for simulated hauls. The estimates from SampleObject appear to be unbiased.

Formulas exist for a multi-stage estimator for the variance of bycatch estimates but we shall employ the use of Monte-Carlo simulations as discussed below to quantify estimate variability.

Monte-Carlo Method

The Monte Carlo method provides approximate solutions to a variety of mathematical problems by performing "brute force" statistical sampling experiments on a computer. The method applies to problems with no probabilistic content as well as to those with inherent probabilistic structure. Thus while this method might seem as overkill under our simple parametric situation, it can provide an effective way to incorporate actual data or implement a more non-parametric approach.

In simple terms, by running a large number of simulations under the same situation, and collecting the numerous bycatch estimates, we can quantify the variability involved in our process. This measure of variability is used in our measure of estimate precision that is discussed in the following section. We will also consider the possibility of using the estimated variability in constructing confidence intervals for our simulated bycatch estimates.

Estimate Precision

The coefficient of variation is a measure of relative variability and is defined to by the standard deviation divided by the mean of a sample,

$$CV = \frac{\sigma_x}{\bar{x}}.$$

This relative measure of precision is used to compare simulation results over various situations, and will provide a practical measure in addressing the issue of enforcement and potential prosecution. Even if variability in a simulation situation is outrageously large, if the vessels involved do not bring in catches that are substantially large then the coefficient of variation will remain large and it might not be economically practical to pursue litigation. Further information from fishery managers and lawyers would be needed to examine exactly under what circumstances litigation is pursued. These circumstances might provide for a precision threshold that could be implemented in the potential formation of cooperatives and enforcement pooled bycatch quotas.

Our Java program MonteCarlo.java allows us to repeat simulations of a fishing season given identical parameters of pool size and observer coverage. We have implemented Monte-Carlo variance estimation techniques to calculate the variability between exact and estimated bycatch weights, σ_x, and the mean estimated bycatch weight, $\bar{x}$. From these statistics we can calculate the coefficient of variation as a measure of estimate precision.

Simulation Results

We have successfully run simulations under simple situations and collected the output needed for analysis. Our simplified fishery consists of only two species of fish, a hypothetical target species such as pollock or yellowfin sole and a hypothetical prohibited-bycatch species such as salmon. Specific biological information, containing normal weight distribution information for each species, is contained in a vector of SpeciesObjects. We make the assumption that target and bycatch frequencies remain at fixed proportions over the entire simulation season.

Our basic fishing process is modeled by selecting quasi-random fish. This is implemented in the HaulObject by using a quasi-random uniform number generator for species selection with specific individual characteristics (e.g., weight) obtained through a quasi-random normal generator with specified mean and standard deviation. This fishing situation could be made more complex by the introduction of multiple species and implementation of more detailed age-specific distributions for each species.

For simplicity in our sampling scheme, observers remain onboard each vessel at all times and sample a fixed proportion (e.g., 50%) of the hauls that are brought in by that vessel. We implement the partial haul observer sampling strategy as discussed in Section 4 and used by our SampleObject class, wherein an observer randomly samples a fixed proportion of the entire haul in order to make their estimates. Again, the sampling strategy can be modified to employ basket sampling or altered to explore possible new sampling methods and observer protocols.

To investigate the implementation of IBQs, simulations are run using pools of vessels. Each pool consists of a number of homogeneous vessels, with a specified pooled catch quota for each target and bycatch species. Each vessel in the pool has a maximum haul size, and we use the median statistics reported in Section 2. To avoid complicating the model, we eliminate the possibility of modeling vessels filling their entire hold and the time needed for processing. This is achieved by setting an enormous hold size that cannot be filled in our given situations. Also, for these simulations we set the target species with a very high catch quota, which allows fishing to continue until the pooled bycatch quotas are overtaken and the pool is shutdown.

Simulations

Choosing a grid of feasible pool size and observer coverage parameter combinations, the simulator is run 100 times under similar conditions to obtain repeated information on the estimated and exact pool weights of the collected bycatch species. From these repeated simulations, the differences between estimated and exact pool weights of the bycatch species are used to estimate the variability as described previously in Section 4. The estimated variance is then divided by the average bycatch weight to obtain the coefficient of variation and the practical measure for the precision of our bycatch estimates. Thus for a given level of variability, the magnitude of the average bycatch weight will effect whether an overage in bycatch is practically significant and warrants prosecution. These parameter combinations with the associated estimate precision are output to a file, which can then be analyzed using the graphical methods described below.

Graphical Analysis

Using the excellent graphical capabilities of Matlab, we read in the simulation output and produce various plots and graphs that allow us to better examine and visualize the relationships and tradeoffs between the choice parameters and the bycatch estimate precision. We produce a 3D surface-mesh plot, as seen below, for the bycatch estimate precision and note that the coefficient of variation decreases, implying increased estimate precision, when either observer coverage increases or pool size increases.

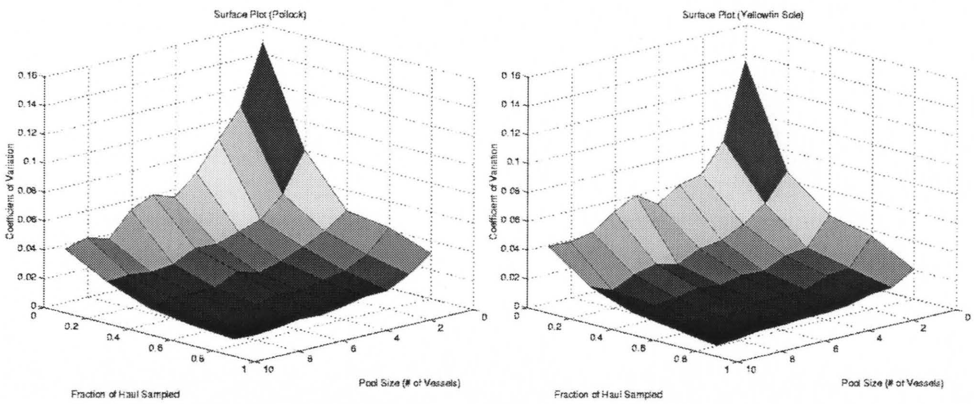


Figure 7.—Surface Plot of estimate precision as pool size and observer coverage are varied for pollock (left) and yellowfin sole (right) fisheries

We also produce contour plots of the above surface, where we can more easily examine the level sets of constant estimate precision. This allows us to investigate what combinations of parameter values combine to produce similar levels of precision. From this we can better understand the tradeoffs needed in pool size and observer coverage to remain at a specified level of precision.

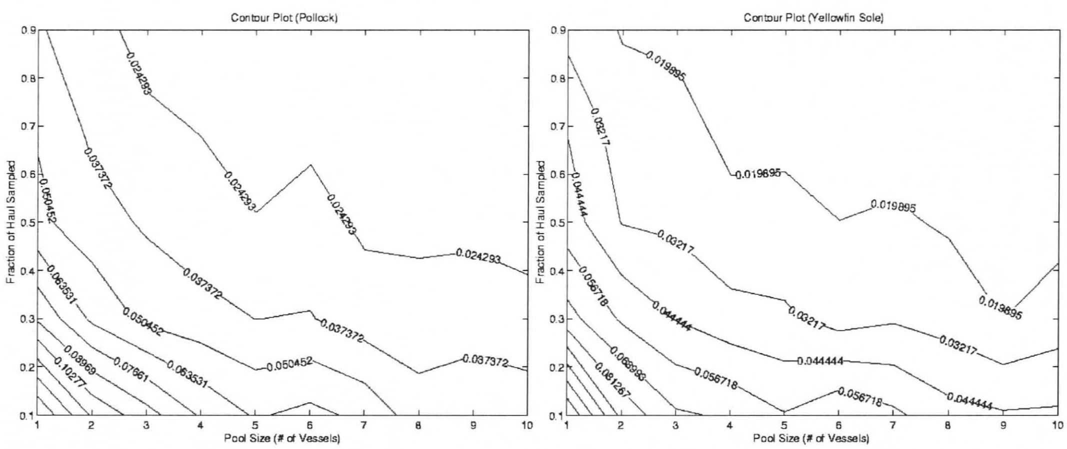


Figure 8.—Contour Plot for constant levels of precision as pool size and observer coverage are varied for pollock (left) and yellowfin sole (right) fisheries

The characteristics of the contour plot might allow us to address certain cost and pool size optimization questions. For example, given a fixed observer coverage level, which in turn influences individual vessel operating costs, what is the minimum pool size that will achieve a specified precision level? Or to what extent is it possible to lower your observer coverage needed to obtain a specific level of precision by increasing your pool size?

The bumpy nature evident in the above plots can be attributed to the small number of repeated simulations used by our Monte-Carlo methods to produce estimates of variability and precision. By increasing the number of repeated simulations at each parameter pair we can further reduce the bumps and kinks seen above. It is hope that information in the above plots will give fishery managers the information needed to develop methods of examining the sampling costs required to achieve a certain level of precision.

We also consider using the estimated variability determined through our repeated simulations to build confidence intervals for bycatch estimates. This might provide an additional enforcement tool useful in determining the statistical significance of estimates that exceed pool bycatch quota levels and provide situations of successful prosecution.

Conclusions

We have created a basic framework in which to examine tradeoffs in estimate precision with various parameters. By assigning bycatch quotas to vessel pools or coops, we are able to increase the precision of bycatch estimates, which supports implementing an IBQ program in fishery management. This research could be further extended to examine precise criteria for coop formation and optimization.

This framework can be easily modified to adapt to more complex modeling situations of fishing and sampling processes, with results that can be easily compared across different circumstances. We look forward to the potential implementation of actual observer data into simulations, which will be used to model observed dynamic changes in bycatch frequency, or catch distribution, throughout a realistic season. Our simulator framework could also be adapted to investigate current issues concerned with catch stratification as species proportions tend to vary among samples taken at different positions in a haul. Coop managers could use these tools to propose and examine difference random sampling structures within their own coop that would ensure a specified threshold precision level while minimizing observer costs.

We also contemplate the possibility of incorporating more pieces of data contained within the NORPAC Database, and are especially excited about implementing and analyzing the relationships between the spatial and temporal variables available. We again wish to emphasize the great potential of this project for use in continuing research, by addressing and investigating problems that can be difficult, if not impossible, analytically.

We also plan on providing a Graphical User Interface to AFSC, running on top of our existing Java code, to facilitate a more effective platform to setup and run simulations. This GUI will provide the possibility of implementing simulations on any computer. This framework could provide a useful tool to fishery managers as more information is to be made public knowledge by AFA about cooperatives and individual vessel bycatch statistics.

References

AFA (American Fisheries Act). 1998.

Alaska Department of Fish and Game and North Pacific Fishery Management Council. 1999. Environmental Assessment/Regulatory Impact Review/Initial Regulatory Flexibility Analysis of a Proposal to Minimize Chinook Salmon Bycatch in Groundfish Trawl Fisheries of the Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, Anchorage, AK.

Alaska Sea Grant. 1996. *Solving Bycatch: Considerations for Today and Tomorrow*. University of Alaska Sea Grant, Fairbanks, AK.

Alaska Sea Grant. *Fisheries Bycatch: Consequences and Management*. University of Alaska Sea Grant, Fairbanks, AK 99775. 1997.

Alverson, D. L., M. H. Freeberg, S. A. Murawski, and J. G. Pope. 1994. *A Global Assessment of Fisheries Bycatch and Discards*. FAO Technical Paper No. 339. FAO, Rome, ITALY.

Dorn, M., S. Gaichas, S. Fitzgerald, and S., Bibb. 1997. Evaluation of haul weight estimation procedures used by at-sea observers in pollock fisheries off Alaska. AFSC Processed Report 97-07.

Gauvin, J. R., K. Haflinger, and M. Nerini. 1996. Implementation of a voluntary bycatch avoidance program in the flatfish fisheries of the Eastern Bering Sea. In: Alaska Sea Grant. *Solving Bycatch: Considerations for Today and Tomorrow*. University of Alaska Sea Grant, Fairbanks, AK.

Jensen, L. S., Internship Report: Fishery Coops and Pooled Bycatch Quotas: Examining the tradeoffs between observer coverage, bycatch frequency, pool size, and bycatch estimate precision. AFSC, July 1999.

Magnuson-Stevens Fishery Conservation and Management Act, Public Law 94-265 as Amended Throught October 11, 1996. NOAA Technical Memorandum NMFS/SPO-23, December 1996.

Manual for Biologists Aboard Domestic Groundifhs Vessels, AFSC 1999.

MSFCMA. 1996. Magnuson-Stevens Fishery Conservation and Management Act, Public Law 94-265 as Amended Through October 11, 1996. NOAA Technical Memorandum NMFS/SPO-23.

National Marine Fisheries Service. 1996. Draft Environmental Assessment/Regulatory Impact Review/Initial Regulatory Flexibility Analysis for Amendment of the Fishery Management Plan for the Groundfish Fishery of the Bering Sea and Aleutian Island Area to Implement an Improved Retention-Improved Utilization groundfish Management Program. North Pacific Fishery Management Council, Anchorage, AK.

National Research Council. 1999. *Sharing the Fish: Toward a National Policy on Individual Fishing Quotas*. Committee to Review Individual Fishing Quotas, Ocean Studies Board, Commission on Geosciences, Environment, and Resources, National Research Council, National Academy Press, Washington D.C.

National Research Council. Sharing the Fish: Toward a National policy on Individual Fishing Quotas. Committee to Review Individual Fishing Quotas, Ocean Studies Board, Commission on Geosciences, Environment, and Resources, National Research Council, National Academy Press, Washington D.C., 1999.

North Pacific Fishery Management Council. 1999. Draft Environmental Assessment/Regulatory Impact Review/Initial Regulatory Flexibility Analysis for American Fisheries Act (AFA) Sideboard Measures, Amendments 61/61 to the Fishery Management Plans for the Bering Sea Aleutian Islands (BSAI) and Gulf of Alaska (GOA). North Pacific Fishery Management Council, Anchorage, AK.

Pennington, M. 1996. Estimating the mean and variance from highly skewed marine data. *Fisheries Bulletin* 94: 498-505.

Pennington, M., and J. H. Volstad. 1994. Assessing the effect of intra-haul correlation and variable density on estimates of population characteristics from marine surveys. *Biometrics* 50: 725-732.

Queirolo, L. E., L. W. Fritz, P. A. Livingston, M. R. Loefflad, D. A. Colpo, and Y. L. de Reynier. 1995. Bycatch, Utilization, and Discards in the Commercial Groundfish Fisheries of the Gulf of Alaska, Eastern Bering Sea, and Aleutian Islands. NOAA Technical Memorandum NMFS-AFSC-58.

Smith, T. P. 1993. Allocating the incidental catch of crab, halibut, herring, and salmon in the groundfish fisheries off Alaska. In G. Kruse, D. M. Eggers, R. J. Marasco, C. Pautzke, and T. J. Quinn II (Editors) *Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations*, Alaska Sea Grant College Program, Fairbanks, AK.

South Atlantic Fishery Management Council/Gulf Fishery Management Council. 1992. Regulatory Amendment to the Spiny Lobster Fishery Management Plan for the Gulf of Mexico and South Atlantic. Gulf of Mexico Fishery Management Council, Tampa, Florida.

Tietenberg, T.H. 1985. *Emissions Trading: An Exercise in Reforming Pollution Policy*. Resources for the Future, Washington, D.C.

Volstad, J., W. Richkus, S. Gaurin, and R Easton, "Analytical and Statistical Review of Procedures for Collection and Analysis of Commercial Fishery Data used for Management and Assessment of Groundfish stocks in the U.S. Exclusive Economic Zone off Alaska." Versar, Inc., 9200 Rumsey Road, Columbia, MD, October 1997.

Volstad, J., W. Richkus, S. Gaurin, and R. Easton. 1997 Analytical and Statistical Review of Procedures for Collection and Analysis of Commercial Fishery Data used for Management and Assessment of Groundfish stocks in the U.S. Exclusive Economic Zone off Alaska. Versar, Inc., 9200 Rumsey Road, Columbia, MD, October 1997.

Witherell, D., and C. Pautzke. 1997. A brief history of bycatch management measures for Eastern Bering Sea groundfish fisheries. *Marine Fisheries Review* 59: 15-22.

Wolter, K.M. Introduction to Variance Estimation. New York: Springer-Verlag, 1985, 427pp.

Zukowski, John. Mastering Java 1.2. San Francisco: SYBEX Inc., 1998.