THE BASIS FOR CHANGE: PART 1 RECONSTRUCTING FISHERIES CATCH AND EFFORT DATA

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ABSTRACT

Rational examination of marine policy requires an analysis of changes in the abundance of species and marine community structure with respect to past policy decisions. Abundance estimates themselves rely heavily on catch and effort statistics. There are official statistics of fish landings for many fisheries of the world. Fishing effort data is generally less available. Unfortunately, for a variety of reasons, landings data do not always reflect actual catches well. For example, discarded catches are left out of official statistics, which developed primarily to demonstrate the value of commercial landings. Illegal or unmandated (not subject to regulated reporting requirements) catches are seldom documented except in candid stock assessment discussions of major species. Through an exhaustive compilation of existing data sources and with the assistance of expert local consultants and/or partnerships, we can develop databases that present a more complete and accurate picture of the catches of marine species, including those of limited commercial significance. The importance of this process is demonstrated by our example from the Canadian North Atlantic fisheries. In this case a partnership arrangement has allowed the inclusion of the discards of fishes, crustaceans and marine mammals based on observer data. An outline of the database required to include and document 'adjustments' to official statistics is presented. This work will be extended to the entire North Atlantic region and beyond.

INTRODUCTION

This paper describes the methods employed in the collection, organisation and adjustment of fisheries catch and effort data used in the '*Sea Around Us Project*'. We will elaborate on our general approach using examples from Canada's Department of Fisheries and Oceans (DFO) and the Northwest Atlantic Fisheries Organisation (NAFO), and the International Commission for the Exploration of the Sea (ICES).

Many countries, particularly those fishing in the North Atlantic, have an excellent record of collecting and reporting fisheries statistics. There have, of course, been inevitable shifts in the format and content of these reports over the long time that seafaring nations have been reporting. These changes have caused numerous problems for the interpretation and analysis of this valuable information. Impacts have affected: species aggregation (typically with commercial species groups now being separated into species), species identification, the units of measure, definition of statistical areas (or their replacement with new systems), degree of coverage of the data collection system and other important measures. Commonly fishing effort data suffer more, as statistical systems evolve with developments in vessels, gear, and fishing practices. Fishing tactics and techniques change over time with targets and fishing areas, which means that 'days at sea' may have different interpretations. Some important measures are difficult to obtain.

Above all, the purpose for which the statistics were collected has changed in many cases. Initially to show the value and development of fisheries, these statistics are now used to manage and maintain stocks. This shift in objectives has caused many distortions, but fundamentally the change is, that before we wanted to know what was landed, now we want to know what was killed. That is, we require the inclusion of all sources of fishing mortality needed to assess the resource, especially if this is to be done in some ecosystem-based way[1]. Patterns of discarding (often altered by quotas or market factors), as well as unreported, misreported and unmandated catches are now important. The spatial distributions of fish stocks and fishing have become important as our understanding of the fishery and the biological processes has developed. These distributions have become valuable as we seek to manage individual fish stocks independently. Our ability to discern spatial patterns is limited by the spatial resolution of catch data and this has varied over time. Quotas, other management measures and international arrangements can all influence the spatial distribution of fishing, regardless of the underlying distribution of the biological stock.

The historical statistics from most countries have focused on the major commercial fisheries, and have largely ignored small scale, artisanal and

[1] Especially if the impacts of fisheries on marine ecosystems are to be evaluated. For example, total fish extractions are required as input to an ECOPATH model.

recreational fisheries. These fisheries are sometimes under jurisdictions other than the traditional national/international reporting bodies. Local knowledge is valuable in obtaining and interpreting statistics on these fisheries sectors and will be vital in reconstructing an historical record for them. The statistics have also frequently ignored or combined the information on catches of less valuable or less abundant species. Again, local knowledge may contribute to enhancing our knowledge of catches from these secondary species

The challenge is to apply informed procedures to improve and unify these historical statistics. Substituting a good guess as a default value for an element of the catch is likely more accurate than assuming by default that it was zero. Documentation of procedures for data adjustment, the basis for the estimates and the authority of the advice used in making the adjustments is essential. The process must be transparent, allowing identification of the reported data and the adjustments made to arrive at the final figures. Only with a transparent and fully documented procedure will it be possible for the agencies that are the primary owners of the data to assess and provide input on the magnitude and quality of the adjusted figures. Many times these agencies have considerable knowledge about discarding, misreporting and other sources of differences between the total catch and the landed catch.

The current uses of fisheries catch and effort data are many and varied. We are attempting to place the data from the North Atlantic in a system that is extendible to the fisheries of the world. As such, our choice of coding and structures has reflected a desire to incorporate fisheries from the extremely small scale to the largest of the factory ships. We are seeking to facilitate analysis of the energy consumption versus production in the fisheries (see Tyedmers, 2000) and this has demanded an approach to reporting fishing effort that is widely applicable (horsepower-days) and based on data that are widely available. Users of catch data will want to reconstruct historical and spatial patterns of exploitation, and in the case of modelling, fishing mortalities. For these purposes, we want to know all sources of fishing mortality (including those not reported in official landings), in the location in which they occurred. The spatial scale of data required for these models varies, but we will strive to produce statistics at the smallest practical scale to allow them to be integrated with larger scale ecological/oceanographic processes (see Pauly et al., 2000).

Our terminology for the various data resources we will discuss is as follows. A dataset refers to the data holdings of a given agency and may include a number of databases. For example, the DFO dataset includes a catch/effort database, an observer database, survey database and many more. A database is a single, coherent collection of data records that will usually be stored in several tables with relational links. Within a database all records will share common coding schemes, units and other standards.

Starting with the global dataset from the Food and Agriculture Organisation (FAO) for world fisheries landings, we have merged in other major datasets that have a geographically narrower scope and finer resolution such as those from DFO, NAFO and ICES. In addition to the greater detail and resolution, these often provide information on fishing effort. These datasets may also indicate different values for the landings data.

To this composite of databases we must make ‘informed’ adjustments and additions. These consist of additional data such as estimates of discards and other unreported catches. Justifications for these adjustments to the ‘official’ statistics come in a variety of forms. In the best cases, these adjustments will come from reliable and documented sources such as observer programs, but which are not included in official landings. In other cases, they may arise from a general discarding rate estimated for a specific fishery, or from estimates of illegal catches from industry or government sources. In some cases, such as ICES stock assessments, these additional sources of fish mortality have been compiled and are used in the stock assessments but are not available in official statistics. In many of these arrangements, the statistics supplied by member states cannot be officially altered even when they stretch the bounds of credibility. In all these cases it is our intention to make the appropriate adjustment, and to credit the source and document the methods used.

Data types

Fisheries data sources contain information of different types, including estimates of landings, measures of effort and a variety of classifiers describing the effort, such as the gear used, the area fished and others. In addition, some data sources attach estimates of economic value or price to the estimates of catch. Integration of data from the various sources, and subsequent adjustments, depends on the standardisation of measures and definitions for all the data types and sources.

Catch and Landings

The most important and fundamental information about fisheries for management purposes is the total catch (Gulland, 1983; Pauly, 1998). Catch is usually classified by species, area, fishing gear used, and other factors. What is officially reported as 'catch' should be nominal catches (the live weight equivalent of the landings). Data on the weight or numbers of animals that were taken but later discarded, even if collected, are not included as these statistics that were designed to describe the contribution of fisheries to the food supply and national economies. The reported catches may be the result of a census of fishing vessel landings, survey sampling, reporting by fishers, or estimated by proxies such as fishing effort. For this paper the reported landings, are nominal catches, and are treated in metric tonnes (t) of live weight (mass) equivalents.

Catch statistics are important for three reasons (1) the gathering of statistics increases knowledge of the fishery (tracking of vessels engaged in fishing, dockside sampling of these same vessels, etc.), (2) total catches determine the scale of the fisheries, both within and between sectors, in terms of their production and value; and (3) examining time series of catches allows for first-order assessment of fisheries, and of the status of the species and populations (stocks) upon which the fisheries depend (see Grainger and Garcia, 1996). Finally, assessments of fisheries and their impacts on fish stocks and the environment have evolved to include other sources of information. However, basic catch statistics are still essential to the process (see Alder et al., 2000).

Fisheries catches may be separated into three components: (1) nominal catches, reported to (and by) a monitoring agency (e.g. by member countries to FAO), (2) discarded bycatch, the non-targeted part of a catch, often consisting of the juveniles of targeted or other species, caught due to the unselective nature of the gear used, and usually thrown overboard rather than landed; and (3) an unreported component, consisting of categories not covered by the reporting system in question (examples may include sport fisheries, artisanal fisheries, or illegal catches). Thus, this last group may be composed of catches that a given agency is not mandated to gather and report ('unmandated catches'), and of catches that are misreported by fishers or others. A major task of our current work is to estimate unmandated and misreported catches, with both requiring the development of new protocols (see Pitcher and Watson, 2000).

Each fishery statistical system we deal with has evolved a set of procedures and conversion factors for reconstituting the original weight of fish landed in a wide range of product forms. The conversion factors (e.g. COFREPECHE, 1996) that are used in each agency's statistical processing are not explicitly considered in our adjustments. It is obvious, however, that if inappropriate conversion factors were used by the agencies providing the catch data, this would lead to significant errors in the live weight equivalents (e.g. converting lobster tails to whole body weights). Note that under quota management systems there may be a tendency for industry to seek adjustment of conversion factors (downward) in circumstances where live weight is being over-estimated. There is, however, no incentive for them to seek any adjustment in the case where live weight equivalents are being under-estimated.

Value and Price

Much of the original incentive for governments to systematically monitor fisheries was to determine the value and economic development of the fishing industry. In some national systems (e.g. Canada), the estimated value of catches (or equivalently, average price) is recorded with the catch data. In other systems (e.g. FAO), economic statistics are generated and reported independently of the catch data.

Effort

As with economic information, fishing effort may be measured and classified, by area, gear, etc, in the same process that records the catch data, or estimated independently. In either case, the effort must be matched to the corresponding catches within the basic statistical system.

The definition of fishing effort, unlike catch, is dependent on the nature of the fishing unit (e.g. boat, trap) and the amount of resources expended by that unit. The specific effort resources expended are routinely measured in units of time and/or amount of gear used but alternative definitions abound. Our work will use three units of effort. The conventional units 'days fished' and 'days at sea' will be compiled directly from the statistical sources. An alternative unit of 'horsepower-days' will be the product of the numbers of days at sea times the average horsepower of the vessels in the given block of effort.

Gear specific effort units, such as hours trawled or thousands of hook-hours seem to offer an apparent finer resolution of effort but they are not used here. Although such detail is available for many of the North Atlantic fisheries, this is not the case for many, or possibly most, fisheries in other parts of the world. Where it is available, the accuracy of gear-specific effort measures has been challenged for many reasons and often by the fishers themselves. Fishers have claimed they had falsified the original logbook data to appear to comply with management restrictions. Regardless of such a concern, the numbers of days fished is a statistic relatively easy to obtain and difficult to falsify. Finally, gear-specific effort units are also difficult or impossible to aggregate across gear types, e.g. relating total number of trawl-hours to hook-hours. On the other hand, horsepower-days offers a comparatively robust measure that can be compared across most fisheries of the world, even those where no vessels are involved.

PRIMARY DATA SOURCES

This methodology review paper deals with data from four primary sources: FAO, DFO, NAFO, and ICES. Each has its own strengths and weaknesses. In addition, information from other datasets, such as those from the U.S. government, the tuna commissions, etc. will be included in our project database. These data will be augmented by smaller, tightly focused datasets, prepared by consultants for a range of European inshore, small-scale and recreational fisheries.

FAO

Only one global database of fish catches presently exists from which inferences can be made that pertain to entire ocean regions: the database assembled by the FAO from reports supplied by member countries (FAO, 1980). This database consists mainly of annually updated catch time series, by countries and regions, for the year 1950 to the present. The quality of the data therein is highly variable, and ranges from accurate data on a single species basis for some countries to crude and over-aggregated estimates for others. Moreover, the catches are not assigned to the Exclusive Economic Zones (EEZ) of the countries for which they originated, but to the large FAO statistical areas for which it is reported.

Few scientists outside the FAO have made use of these statistics to draw inferences on fish stock status over large areas of the world's oceans (but see Alverson and Dunlop, 1998 for exceptions), but content themselves with citing assessments made by FAO staff. There has been little independent validation of this database against original or other data sources. Perhaps there is little criticism and crosschecking because so many countries and institutions contribute to this dataset that has engendered a strong sense of ownership. Nevertheless, its weaknesses in the face of current needs are understood. The FAO Advisory Council on Fisheries Research has admitted; "the current statistics collection system is limited primarily to landings and commodity statistics, whereas there is a critical need for data relevant to fleet capacity, participation in fisheries, economic performance and distribution" (Anon 1997). There have been calls for the FAO reporting areas and species groupings to be changed to reflect current fisheries practises, which would facilitate analysis of the economic efficiencies of fisheries (Pontecorvo, 1988). Such changes would probably facilitate improved biological analysis as well.

Canada Department of Fisheries and Oceans (DFO)

This dataset includes records of Canadian (that is Canadian vessels only) commercial catch and effort per species (marine finfish, invertebrates and plants) for Eastern Canada for years 1986-1998 broken down by spatial statistical regions called 'unit areas'. This dataset is obtained in the Zonal Interchange File Format (ZIFF) and has been compiled within the Atlantic Canadian fisheries regions to ensure consistency of coding and units from the four different statistical offices that operate in the zone. It includes date, target species, unit area, tonnage for each species landed, vessel characteristics (tonnage, tonnage class, length, horsepower) and gear. Records may not include complete vessel characteristics, and therefore, horsepower or tonnage may be missing. The *Sea Around Us Project* will aggregate the DFO data to the level of effort by month, unit area, tonnage class, fishery type and gear type. The catch is further classified by species. The DFO catch data includes all fishery catches with the exception of recreational catches (generally considered small with respect to the commercial fisheries). There are several small-scale fisheries that either have not collected effort data or have only begun to do so recently i.e., in the 1990's.

Northwest Atlantic Fisheries Organisation (NAFO) data

The NAFO dataset includes monthly catch (marine finfish and invertebrates) and effort by divisions only (which may comprise several unit areas in the DFO system) for Canadian and foreign vessels. The data is structured by fishing country, vessel and gear types, and species targeted. The information gathered by NAFO is a compilation of the catch and effort as declared by each member country. NAFO and its predecessor the International Commission for Northwest Atlantic Fisheries (ICNAF) provide a consistent statistical data series since 1960. In order to prevent duplication of records with the DFO dataset we have removed records of catch/effort by Canadian vessels after 1985. This dataset does not include any information for vessel horsepower. A significant number of foreign vessels have been recorded at one time or another in the DFO records of vessel characteristics, including horsepower, and these records will be used to estimate horsepower from the tonnage and other characteristics available in the NAFO vessel records.

International Commission for the Exploration of the Sea (ICES) North Sea data:

ICES data for the North Sea comes from two sources. Electronic data sets exist for all ICES areas (including the North Sea) landings back to 1973. These data are broken down by statistical area and reporting country for the major species. Data provided to us did not include fishing effort or vessel descriptions. There is no official electronic dataset of landings prior to 1973; we therefore used the records provided in ICES' *Bulletin Statistique des Pêches Maritimes (des pays du nord de l'Europe*) to enter landings for the North Sea from 1903 until 1974. From this written record we also extracted what exists of fishing effort records including breakdowns by tonnage class, and more rarely by vessel horsepower.

Consistency of Data Sources

Consistency comparisons between NAFO and DFO datasets will be made, as will DFO, NAFO and ICES with FAO. This will help to determine if the national and international reporting systems are treating data consistently and completely. Comparisons will be limited to the large-scale aggregates used in the FAO dataset. However discrepancies can be investigated with the more detailed data available in the other sources.

Consultations

Official catch and effort statistics are available for most areas of the world. An aggregated set of this data is usually provided to the FAO for inclusion in their global dataset. In order to provide complete details of fish effort and fishing fleet composition, it is usually necessary to access national databases directly. In the case of European Union countries, these data is compiled across member states and are available on the internet.

Obtaining records of small-scale (typically inshore), artisanal, and recreational fishery catch and effort statistics is more problematic. This usually requires either a co-operative or consultative arrangement with some agency/individuals within the country in question. Our project has engaged consultants to report on the inshore, small-scale and recreational catch for the majority of maritime nations in the North Atlantic region. At present we have consultants working on fisheries in Iceland, the U.K., the Irish Sea, Denmark, Norway, France, the Netherlands, Germany, Spain, Portugal and Morocco. Plans exist to extend these efforts soon to Belgium, Russia, and the Azores and Faeroe Islands.

Our co-operative arrangement with the DFO has allowed estimates of discarding to be made based on their observer program. These valuable collaborative arrangements, however, are rare. Alverson et al. (1994) provides a range of discarding for major fisheries that can be applied where appropriate. Such extrapolations from similar fisheries (with respect to gear and target species) must be carefully applied. However, these estimates, untested as they are in most cases, most likely yield a fairer interpretation of total mortalities than ignoring discards where they are known to occur.

Illegal catches are probably the most difficult information to obtain, as they are seldom discussed in official statistics (Creed 1996). Some attempts to make allowances for 'misreported' catches through modelling look promising (Patterson, 1998). Usually these catches can be inferred from other fisheries. Typically, however, interviews must be conducted with informed sources within the fishery or monitoring agency. Personal networks are invaluable for this. A generalized approach based on historical changes in fisheries management or other factors affecting

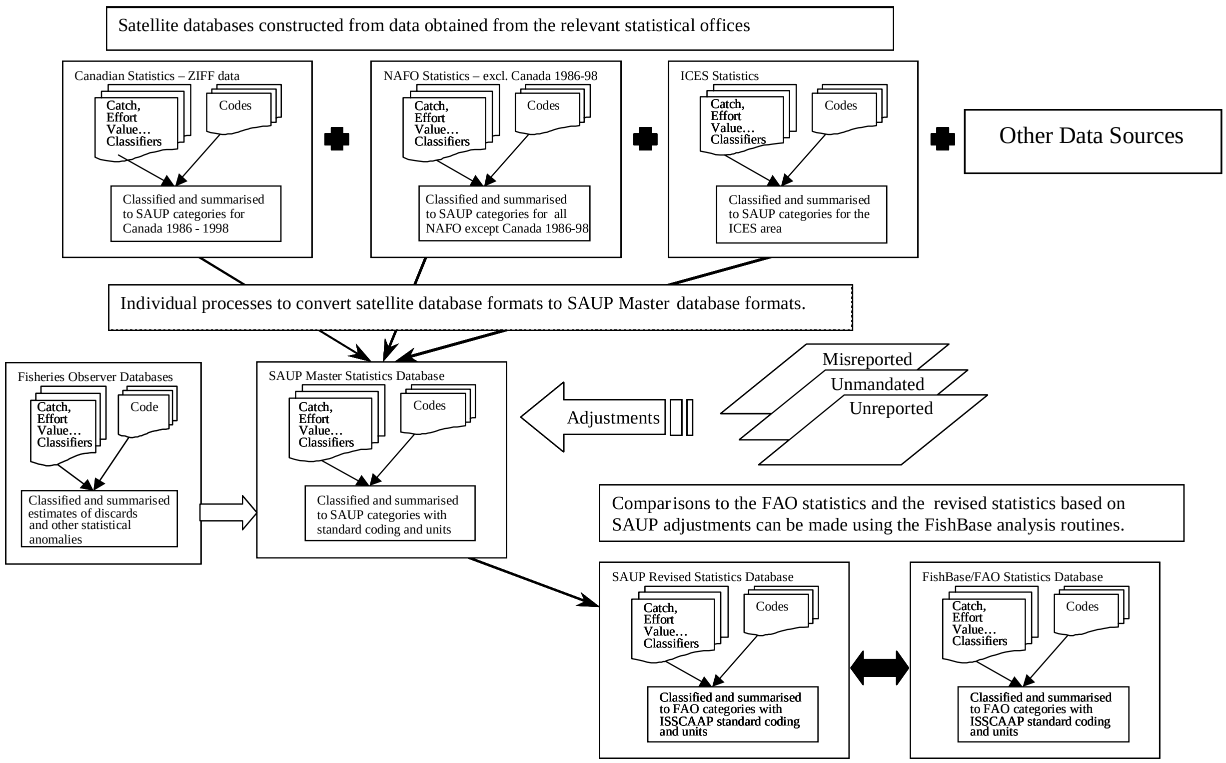

Figure 1. Overall data acquisition, data processing and data management supporting the *Sea Around Us Project's* reconstruction of actual fish catches from the North Atlantic.

incentives to cheat can be informative here (Pitcher and Watson, 2000). Though many official statistics may be difficult to access the trend is for this to change. 'Freedom of information' acts have removed legal impediments, and improved information technology has contributed to widespread and simplified access in several countries including Canada and the U.S. Nevertheless the work of key individuals in each country being reviewed is invaluable. It provides a means of contacting local artisanal and recreational fisher groups who can be very co-operative if properly approached. It provides a means of accessing available port records, some of which have impressive historical spans. Most importantly, having a person within the country allows fishers and government officials to be interviewed 'off the record' so that estimates of illegal fishing, discarding and other vital 'unofficial' statistics can be elucidated.

DATABASE REQUIREMENTS

Design of the project's principal, i.e. 'Master', database was constrained by several imperatives. Unlike a conventional database developed by a government department or a business we could not scale our resources (money, personal etc.) with the scope of our coverage. Indeed some of our imperatives required a smaller, less-commercial approach (such as the choice of MS Access® as our database).

The first imperative was the strong desire to provide an output of summarised catch data compatible with the 15,000 species of marine fishes included in FishBase (Froese and Pauly 2000; www.fishbase.org). This would allow the wealth of descriptive data (taxonomic, life history, occurrence etc) and the significant investment in analytical procedures (trophic level comparisons etc.) to be utilised. Likewise we also wished to maintain, as far as possible, compatibility with the FAO global dataset including its ISSCAAP species codes. Updates from FAO will be valuable to our future work, as no other agency has a mandate or the resources to produce a truly global dataset.

The second imperative was for the database to allow allocation of catch and effort to spatial strata representing functional ecological entities such as large marine ecosystems (see Pauly et al. 2000). Meta-analysis of spatial data would certainly require the use of geographical information systems. Our database must facilitate the use of the data by experts developing models of marine ecosystems.

Thirdly, we wanted to maintain a system of 'satellite' databases (Figure 1) recording the best estimates of catch and effort as supplied by the source agencies. Each satellite database will retain the codes, units and standards of its source agency, but the records will be processed to the *Sea Around Us Project* codes, units and standards into our master database. Thus each original satellite database record will be associated with a Master database record where all the subsequent adjustments and additions can be made in a rigorously documented manner. In this way an 'audit trail' will exist to link incoming data to our final estimates. It should be noted that the resolution of the data in the satellite databases (spatial, temporal, effort, gear, etc.) may vary, however, all will be processed to the standard resolution of the project master database as they are loaded.

The fourth and final imperative was that as rapidly as possible the information would be available to all, preferably on the Internet and with a map-based interface. In this way it would be used/improved by experts, and contribute to debates on the state of marine systems and marine policy in general.

DATABASE STRUCTURE

Catch

Species Codes

The database utilises the ISSCAAP codes used by FAO, but will allow synonymy with other coding systems. The codes, broadly compatible with the fish classification in FishBase (itself based on that of the California Academy of Science), will allow identification at a variety of taxonomic levels and allow processed products to be differentiated from whole products.

Catch Value

Catch values, based on average prices not corrected for inflation, for three broad periods (1950s, 1970s and 1990s), as well as their major markets (Sumaila et al. 2000), will be included for each taxonomic group to allow estimation of catch values.

Fishing Effort

The method of describing fisheries and fisheries effort used in this project was designed to be extendible to other fisheries around the world, some of which are very different from those dealt with in the North Atlantic. The 'taxonomic' approach allows any fishery to be characterized by its basic gear type, its location, the tonnage class of vessels used (if any), and the major target species. This system draws upon the descriptions of world fishing gear by Brandt (1984). Those fisheries that can be confused by two of these descriptors can be separated by the third. We plan to further characterize these fishing effort groupings by the average 'catching power', that is the amount of the target species typically landed for each fishing day or day at sea (when abundance is high) with the usual number and configuration of gear units (hooks, nets, whatever) employed. This will facilitate comparison of small and large-scale fisheries (see Ruttan et al., 2000).

Time Periods

Though some data sets provided to us, such as that from DFO Canada, contain detailed fishing effort aggregated to month, we have further aggregated these records to annual records as we are primarily interested in examining changes over longer periods. The original monthly information will assist in studies of the seasonal aspects of these fisheries, and allow us to formulate a more precise spatial allocation of catches and fishing effort. Some of the Canadian data is available by fishing gear set by the date of the fishing activity rather than the date of landing.

Fishing Areas

As with catch data, it is important to be able to aggregate fishing effort into spatial definitions such as large marine ecosystems (see Pauly et al., 2000) that we believe to be the correct scale to examine the impact of management changes. Data from DFO Canada was provided by 'unit area', these are smaller areas that nest within NAFO statistical areas. ICES data were broken down into ICES statistical areas. Where possible and appropriate, expert consultation will be used to determine appropriate rules to allocate catch and effort to the smaller units which will facilitate their re-aggregation into units of ecological or management significance (for example Large Marine Ecosystems).

Gear type

Although all the statistical systems record a wide variety of fishing gears, we have grouped them into a much smaller number (see list below) which ignores the details of gear construction but is based on the primary mode of fish capture or gear operation. For example, hand line and longline are in the same category because their efficiencies do not depend upon a particular boat

Table 1. Fishery types for the North Atlantic.

Groundfish	Demersals e.g. cod, flounders, redfish
Small Pelagics	herring, mackerel
Large Pelagics	tuna, swordfish
Sharks and Skates	Porbeagle, dogfish
Freshwater or Diadromous	alewife, smelt, eels
Bivalves	clams, quahaugs
Scallops	
Squid	
Lobster	
Shrimp	
Crab	
Miscellaneous	Seaweeds, lumpfish

size. Harpoon and spear are quite rare in this data set and include sealing and swordfish. The dredge group includes both hand-held and mechanical devices because the hand-held one is rare, and each of them will be used with distinctive vessel sizes.

Gear types are:

- bottom trawls,
- midwater trawls,
- mobile seines,
- surrounding nets,
- gillnets and entangling nets,
- hooks and lines, trap and lift nets,
- dredges,
- grappling/wounding, harpoons and spears, and
- other gear.

Fishery Types

Although approximately 50 species account for 95% of the nominal catch reported to FAO from the North Atlantic since 1950, there are still many more species that are caught but not landed or reported. In most catch statistics, the target species is in fact the more abundant species on a trip by trip basis. This is sometimes called the 'main species caught'. There are exceptions, however, such as tropical shrimp fisheries, which often take many times the quantity of small demersal fin fishes than shrimp target species. The number of target species for the fisheries of the world is potentially a very long list. Thus, it is more useful to group the target species into broader fishery types that reflect the choices that fishers are really making: fishing for groundfish, small pelagics, squids, etc. (Table 1).

With these categories, the assignment of effort to fishery types is less subject to interpretation than the assignment to species sought or even 'main species caught' groupings. The fishery types defined here serve as links to observer data that will provide a minimum estimate of discards produced by each fishery.

Vessel Size

The most widely available descriptor of vessel size is its overall length. Unfortunately, trends in vessel design, at least for the North Atlantic, have resulted in large increases in the displacement of vessels within regulated length groups. As a result, the relative fishing power over time is best described by tonnage. There are long standing tonnage classes (Table 2) in use on both sides of the Atlantic and they are used here. Where necessary, we will convert from vessel length to vessel tonnage.

Table 2. North Atlantic vessel tonnage classes.

Not known	(for Canada most are 0-24.9)
0-49.9	
0-24.9 25-49.9	This split used in Canada only
50-149.9 150-499.9 500-999.9	
1000-1999.9	
2000 or greater	

Adjustments

Adjustments made to catch and effort data (as imported from 'satellite' databases) will be documented on a species-time-area-gear basis so that changes in values can be review and updated.

CASE STUDY: CANADIAN NORTH ATLANTIC (DFO AND NAFO DATA)

Our approach can be illustrated by the process of reconstructing the catch and effort for the North Atlantic region under the jurisdiction of Canada's DFO and NAFO. This case demonstrates what is possible under co-operative arrangements in 'data-rich' fisheries. In other circumstances where the unaggregated data are not available, approaches based on more general considerations, e.g. average rates of discarding for aggregated areas or times (Alverson et al., 1994), are necessary. Even in circumstances where conventional datasets are complete and well maintained, the difficult task of estimating totals for discards, misreported, and unreported catches may call for a different approach (Pitcher and Watson, 2000).

Species Identification

Species codes and names were rendered uniform across three data sets: the DFO research, Canadian commercial catch, and NAFO. Coding inconsistencies were traced and corrected when possible. Because they are the direct links with the observer data, the DFO research species codes were kept. Nine categories were added to the research species list: marine plants, sub-products of already accounted for catches (e.g. seal and cod liver), and unconvertible products (Table 3). The unconvertible products category refers to products for which the yield of processed products varies significantly across area, fishers, and time, so as to make difficult the estimation of an accurate live weight. Marine mammals catches were not part of the fishery data and are described in a specific section (see Appendix 1).

Table 3. Categories of products unconvertible into live weight biomass.

Description	Examples
Sub-products of catches already accounted for elsewhere	seal and cod liver, seal oil
Unconvertible products	sea urchins roe
Marine plants	kelp, Irish moss, rockweed

Catch reconstruction

For the years 1986-1998, the Canadian catch was obtained from the 'zonal interchange files' (ZIF files) while the foreign catch came from NAFO data. The foreign catch is defined as the catch reported by vessels registered in other countries. For the years 1960-1985, all catches were obtained from the NAFO data set.

Catch was compiled by year, month, country, NAFO division, unit area, vessel size, gear type, fishery type, and species.

Not all aspects of marine harvest are covered equally by the DFO database. One component that is missing is the take of marine mammals, especially seals. A reconstruction of seal harvests is described in Appendix 1.

Effort Reconstruction

Canadian data 1986-1998

Effort is defined as the number of horsepower-days, that is, the number of days spent fishing (includes searching and fishing) or days at sea (includes fishing days plus travel time), structured by gear, year and month. The direct approach would normally be to match vessel characteristics to each fishing trip. However, because of frequent missing vessel characteristics, and because small Newfoundland vessels were not individually linked with their catches, several intermediate steps were necessary to generate estimates of horsepower.

Where missing, the vessels horsepower was replaced by an estimated value based on a linear regression using vessel length and tonnage. Vessels present in the database (actually fishing or not) were used if complete information for their length, tonnage and horsepower was available. A preliminary exploration of the data showed a skewed distribution for horsepower, warranting a fourth root transformation to stabilize the variance. The resulting linear predictor of transformed horsepower was

$$HP_l = 1.844 + 0.0379 * \text{length} - 0.0017 * \text{tonnage} \quad \ldots 1)$$

Retransformation, accounting for the retransformation bias gives

$$HP = HP_l^4 + 6\sigma^2 HP_l^2 + 3\sigma^4 \quad \ldots 2)$$

An alternative estimation of the horsepower using a generalised linear model and appropriate link may provide for improved precision without the problems of retransformation bias. A comparison of these two estimation approaches will be made for these data.

For each trip, horsepower was obtained by using the horsepower attributed to the vessel that reported that catch. Missing horsepower were replaced by the average value computed for each stratum (combination of year, month, tonnage class, gear type, and fishery type). The remaining missing values were replaced by averaging horsepower over progressively larger combinations of categories (blocks of effort) until all missing values were estimated (Table 4.)

Effort was then computed as the amount of horsepower multiplied by the number of fishing days spent. Because effort was often missing, a distinction is made between catch associated with and without effort so that total effort could be scaled from reported effort.

Effort adjustment for catch without effort

Total effort will be computed for each effort cell as the total catch for all species divided by the catch rate for all species. Each cell will have a unique factor and will be referenced in the database to our methods. Application will depend on the data source as some may have already applied effort prorating.

Table 4. Procedure used to estimate the average horsepower in each block of effort.

Descriptors used	Remaining missing values
Year, month, NAFO divisions, tonnage class, gear type, fishery	47,127 (41%)
Year, NAFO divisions, tonnage class, gear type, fishery	9,736 (9%)
NAFO divisions, tonnage class, gear type, fishery	5,061 (4%)
NAFO divisions, tonnage class, gear type	674 (<1%)
Tonnage class, gear type	0

Discarding

Observer Programs

The use of at-sea observers is a widespread practice in large-scale fisheries. In the Northwest Atlantic there are observer programs operated by Canada, based in Nova Scotia, Newfoundland and the Gulf of St. Lawrence, and by NAFO. At-sea observers supplement the much more limited amount of surveillance conducted by the fisheries enforcement agencies. Observer data contains a voluminous amount of information but caution is required in the analysis. Observers are not deployed in a random manner, nor in fact is there usually a sampling design intended to minimise variance or control bias. Observers are often deployed in a 'tactical' manner, meaning the enforcement agency is concerned about a particular area or the fishing practices of a particular vessel, and send an observer in response. Observer data has been challenged over the years with accusations of corruption. However, very few of these have ever been substantiated. The greatest challenge in analysis of observer data is the effect that the presence alone of an observer has, or may have, on the fishing practices of a vessel, i.e., an observer effect. One expected observer effect would be for captains to not commit infractions of the regulations while carrying the observer.

Fisheries observers routinely spend a full trip on board vessels. They record the positions fished, the effort used and the composition and fate of the catch taken. The data is far more detailed than is possible to collect with a logbook and is independent of either willful or negligent inaccuracies on the part of the ship's Captain. The characteristics of the vessel and gear are recorded at the beginning of the trip and any gear modifications are recorded as the trip progresses. The effort is recorded by date, time and position (latitude/longitude), the amount of gear and duration fished, conditions of weather and sea during fishing and any gear damage or other events arising during fishing. The catch is observed and total catch for each species is estimated, including amounts kept and discarded. As many vessels operate 24-hours a day, the observers update their records from the logbook whenever they were off-duty.

Many species that never appear in the reported catch statistics are recorded by the observers, for example, on the eastern Scotian Shelf (Nova Scotia, Canada) in 1986 there were 125 species observed in the catch, while there are only 42 reported in the corresponding NAFO database. Some of these 42 include groups of species such as sharks that are routinely separated by observers but others, such as skates, are completely unaccounted for.

A description and application of the approach to catch adjustment using observer data is worked out for a particular block of data in the following sections. The data is from 1986 and covers the groundfish fishery on the eastern part of the Scotian Shelf in NAFO divisions 4V and 4W (Figure 2). The catch statistics are obtained from the NAFO databases maintained by the Canadian Department of Fisheries and Oceans (DFO). These data have been included in The Sea Around Us database as described above. The observer data comes from the DFO observer database maintained at the Bedford Institute of Oceanography by Marine Fish Division, Maritimes Region of DFO. Most of the analysis was completed using database queries in ORACLE although the same results could be obtained by various other means. The block of data was selected for this example because it is data-rich and allows a good demonstration of the methods. It is acknowledged that many other fisheries, areas and times are not as well covered, and adjustments to such catches will be based on less data and broader application of the mean catches from other places and times.

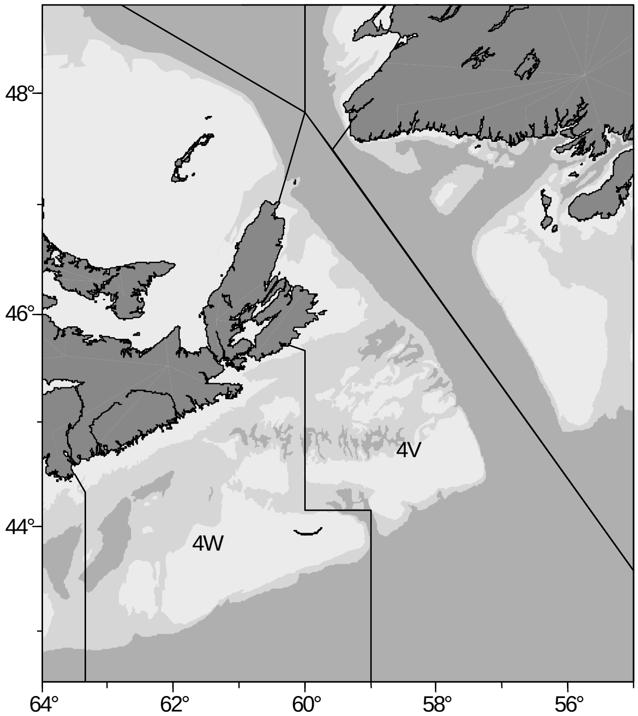

Figure 2. Area of discard estimation (NAFO's Divisions 4V and 4W) as outlined on the eastern portion of the Scotian Shelf off Nova Scotia. Canada.

A further point regarding the example block of data is that during 1986 it was not illegal to discard fish, in any quantity and of any species. For this reason, there was less likely to be an observer effect limiting this behaviour. It has been reported that fishing captains were still reluctant to discard excessively when observers were present, even in the absence of any specific regulation against it. Consequently, an observer effect, inhibiting discarding practices, cannot be ruled out and so the estimated discards, even for this period of time, must be considered minimum estimates, especially for target, high-valued species.

Estimation of Observer Coverage Proportions

All results from at-sea observers must be interpreted carefully in light of variable and often low coverage levels for certain fisheries. We have defined coverage rate to be the proportion of the reported landings for a given unit of data, i.e., country, area, month combination, which was observed as retained catch by the observers. The proportions reflect the total amount of retained catch of all species by weight, observed at sea with respect to the total amount of landings reported for the corresponding country, area and month. Proportions greater than 1.0 reflect observed catches in excess of the total reported landings. Thus, observer coverage proportion, $O_{c,a,m}$, on a catch basis is:

$$O_{c,a,m} = \Sigma_s \, kept_{c,a,f,y,m,s} \, / \, \Sigma_s \, C_{c,a,m,s} \qquad \text{...3)}$$

where $kept_{c,a,f,y,m,s}$ is the total observed landings and $C_{c,a,m,s}$ is the nominal catch (landings) in the NAFO data.

Table 5. Coverage proportions by Canadian fisheries at-sea observers during 1986, for the groundfish trawler fishery in NAFO 4VW in 1986. Empty cells have no observer coverage, 'no catch' indicate that fishing was observed but no catch was reported to NAFO, grayed cells mean that there was neither reported nor observed catch. Figures represent the ratio of a nation's observed catch to that nominal catch reported by that nation for the same month and statistical. Values exceeding 1.0 indicate that the observed catch exceeded the catch subsequently reported to NAFO.

	Canada		Cuba		France	Japan		USSR	
Month	**4V**	**4W**	**4V**	**4W**	**4V**	**4V**	**4W**	**4V**	**4W**
1	0.07				1.34				
2	0.09	0.28			0.10				
3	0.14	0.00			0.00	1.40	no catch		
4	0.02	0.01		0.47	0.77				
5	0.18	0.06		0.58	1.13				0.51
6			no catch	0.06		1.58		no catch	0.42
7	0.02	0.02	no catch	1.00		1.94		no catch	0.23
8	0.09	0.00		0.53		1.68	no catch		
9	0.14	0.01							
10	0.08	0.06				1.65			
11	0.06	0.00							
12		0.00							

Table 6. Estimates of discards (tonnes) by month and species in the groundfish trawler fishery in NAFO area 4VW in 1986. (* refer to unspecified species).

Common Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Alewife		0.05		0.12	0.00	0.00							0.17
American plaice	45.92	9.63	103.54	0.10	14.61	1.80	3.60	26.01	12.17	10.22	0.00		227.59
Argentine			0.01	0.06	0.14	1.83	0.02	7.57	0.00	0.07			9.70
Bigeye tuna										0.00	0.00		0.00
Bluefin tuna							1.28		0.00	0.00	0.00		1.28
Cetaceans						3.69							3.69
Cod	68.70	234.49	281.96	0.01	55.72	1.20	170.69	292.89	39.22	50.66	0.17	0.00	1195.72
Crustaceans	1.80	0.41	0.47	0.44	6.25	15.94	5.79	2.49	0.32	0.19			34.10
Cusk	0.00	2.08	0.00	0.15	0.11	0.51	0.00	2.60	0.00	0.18	0.00	0.00	5.63
Dogfish*	27.16	164.92	1608.20	462.03	476.99	33.03	2.56	23.36	0.40	0.67			2799.33
Flounder*	0.00	0.29	0.97	0.00	0.37	0.00	0.00	0.00	0.00	0.00			1.63
Grenadier								0.00					0.00
Groundfish	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Haddock	48.10	109.63	93.55	0.00	29.06	2.89	50.66	162.14	30.96	89.54	38.00	0.00	654.53
Hake*			0.01	0.00	0.30	0.00	0.00	0.00	2.22	0.06			2.60
Halibut	0.00	0.25	0.02	0.00	0.00	0.16	0.00	12.60	0.00	0.00	0.00	0.00	13.03
Herring	0.00	0.17		0.00	0.67	0.48	0.00	2.53	0.01	11.69	8.00		23.54
Mackerel		0.04		0.00	0.09	7.89	9.21	5.36	0.04	0.03	0.00	0.00	22.65
Monkfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other fish sp.	10.84	8.94	1.32	2.64	34.53	11.46	73.77	103.87	13.03	38.45	2.69		301.55
Other inverts	0.12	0.01	0.40	0.00	2.91	30.20	0.06	759.98	0.16	4.11			797.94
Pollock	11.26	115.62	64.99	0.11	61.17	0.94	60.60	19.64	4.93	6.25	0.00	0.00	345.51
Porbeagle		0.89		0.65	1.06	0.12				1.56			4.29
Red hake	0.00	75.15	4.58	0.71	1.02	5.54	0.01	3.58	0.02	0.11			90.72
Redfish	7.73	3.52	13.16	0.00	6.01	0.40	1.62	85.94	1.59	9.69	0.35	0.00	130.00
Seals*	0.11	0.32	4.48		0.79	4.77	0.32						10.78
Sharks*				0.04	12.33	1.19	2.98	1.79	0.37	26.66			45.36
Silver hake	5.23	17.09	1.52	32.68	47.85	200.94	11.10	11.60	1.90	81.18	0.00	0.00	411.10
Skates*	174.03	383.03	501.45	327.25	266.96	6.22	414.42	224.60	244.19	313.38	86.29		2941.81
Swordfish					0.00	0.48	0.00	0.18	0.00	0.00	0.00		0.66
Turbot		0.00	0.00		0.00	0.00	0.00	0.04	0.00	0.32			0.36
White hake	0.01	0.93	0.34	8.69	0.89	5.99	1.52	45.73	2.33	10.45	0.00	0.00	76.88
Winter flounder							0.00			0.00			0.00
Witch flounder	14.96	1.03	54.18	0.02	0.41	0.03	0.04	0.62	0.39	0.03	0.00	0.00	71.72
Wolffish*	0.98	1.46	0.54	0.01	1.01	0.10	0.05	27.72	1.47	3.64	0.00	0.00	36.98
Yellowtail fl.	2.11	0.02	0.14	0.00	10.46	1.19	90.21	77.68	55.62	71.23	0.00	0.00	308.67
Totals	419.08	1129.97	2735.83	835.72	1031.69	338.99	900.50	1900.51	411.35	730.38	135.50	0.00	10569.30

* unspecified

Table 5 highlights several of the problems inherent in this approach. Cells highlighted in grey contained neither reported catch nor observed catch, so do not represent a problem. Empty white cells correspond to catches with no observer coverage at all. Cells indicated as ‘no catch’ correspond to instances of observers reporting fishing, with retained catches, from times and areas but for which the country in question did not report any catch at all. In the six cases below, it is likely that the vessels were in part fishing in adjoining areas, i.e., 4V or 4W, and that their catches were reported as such. The other problem revealed is the occurrence of cases in which the observed catch exceeds the reported catch.

Estimation of discard catch rates

In this example, the observer data (Table 6) and the corresponding reported catches for the groundfish trawler fishery in NAFO 4VW in 1986 was the compiled weight of both kept and discarded catch by month (m), country (c), NAFO area (a), and species caught (s). Estimates of discard rates, $d_{c,a,m,s}$, were obtained by linking the observer program data and the reported catch for each block of effort,

$$d_{c,a,m,s} = disc_{c,a,m,s} \, / \, \Sigma_s \, kept_{c,a,m,s} \quad \text{...4)}$$

where $disc_{c,a,m,f,y,s}$ is the total observed discards for species s and $kept_{c,a,m,s}$ is the observed landings. The estimated discards, $D_{c,a,m,s}$, are computed as:

$$D_{c,a,m,s} = d_{c,a,m,s} * \Sigma_s \, C_{c,a,m,s} \quad \text{...5)}$$

Table 7. Summary of example results of observer-based estimates of total discards (tonnes) for all species combined, for the groundfish trawler fishery in NAFO 4VW during 1986.

Month	Canada		Cuba		France	Japan		USSR		Monthly Totals
	4V	4W	4V	4W	4V	4V	4W	4V	4W	
1	400	0			19					419
2	852	212			67					1130
3	1090	1632			0	14	0			2736
4	330	0		505	0	0	0			836
5	411	31		311	1				277	1032
6	0	0	0	243		5		0	92	340
7	868	42	0	0		4		0	8	921
8	713	1149		18		21	0			1901
9	387	24		0		0	0			411
10	598	128				5				731
11	69	66				0	0			135
12	0	0				0				0
Totals	5717	3284	0	1078	87	49	0	0	377	10592

where $C_{c,a,m,s}$ is the reported catch in the NAFO data. The individual estimates of discarded catch are summarised by species and month in Table 6, by month and country in Table 7 and totalled by species (Table 8) below. The difference between the total in Table 7 (10592) the other two (10569) occurred because a small amount of catch (23 t) had no species identity assigned to it. This is often accounted for in a category called NEI (not elsewhere included).

The analysis presented here will be extended to better estimate discards from cells without observer estimates through application of generalized linear modelling. One specific approach may be a logistic model for the rates. However, other alternatives will also be investigated. This approach opens the way to using the EM algorithm for filling in missing cells. Interviews of fishers participating in various fisheries provide a semi-quantitative means of estimating discard. However, these are usually specific to particular times and areas, and great care must be exercised when applying them to large aggregates of data. For this reason, data from this source should be given greater weight as a means of setting ‘anchor points’ in the more qualitative discard estimation of Pitcher and Watson (2000).

Illegal Catches

Enforcement and surveillance program

Estimates of illegal catches taken by both foreign and domestic vessels could potentially be estimated from fishing vessel surveillance data (DFO Conservation and Protection Branches in the Atlantic regions). Their data is confidential and considered sensitive but if kept anonymous, it may be possible to use and analyse their data to

Table 8. Comparison of estimated discards and reported landings for the groundfish trawler fishery in NAFO area 4VW for 1986, all countries combined. The table is ordered in descending order of the proportion (percent) of discards in the total catch (tonnes).

Common Name	Catch	Discard	Percent
Grenadier	1	0.0	0.0
Bigeye tuna	10	0.0	0.0
Groundfish (unspec)	76	0.0	0.0
Monkfish	2081	0.0	0.0
Swordfish	231	0.7	0.3
Silver hake	82466	411.1	0.5
Mackerel	2202	22.7	1.0
Halibut	1132	13.0	1.1
Cod	79084	1195.7	1.5
Redfish	7621	130.0	1.7
Cusk	326	5.6	1.7
Pollock	19296	345.5	1.8
Flounder (unspec)	68	1.6	2.3
Witch flounder	2382	71.7	2.9
Turbot	12	0.4	2.9
White hake (Squirrel)	2341	76.9	3.2
Haddock	16384	654.5	3.8
Wolffish (unspec)	309	37.0	10.7
Bluefin tuna	9	1.3	12.4
Red hake (Squirrel)	257	90.7	26.1
Yellowtail flounder	692	308.7	30.8
Alewife	0	0.2	100.0
Hake (unspe	0	2.6	100.0
Cetaceans (unspec)	0	3.7	100.0
Porbeagle	0	4.3	100.0
Argentine	0	9.7	100.0
Seals (unspec)	0	10.8	100.0
Herring	0	23.5	100.0
Crustaceans (unspec)	0	34.1	100.0
Sharks (unspec)	0	45.4	100.0
American plaice	0	227.6	100.0
Other fish species	0	301.6	100.0
Other invertebrates	0	797.9	100.0
Dogfish (unspec)	0	2799.3	100.0
Skates (unspec)	0	2941.8	100.0
Total/Average	216980	10569.5	4.6

obtain an estimate of illegal catches including areas outside the 200 miles limit (but see Pitcher and Watson, 2000). Such estimates would provide the basis for adjustments to the catches reported to NAFO.

Consultants are currently engaged by the Project to obtain catch records from the home ports of Portuguese and Spanish fleets which have fished in the Northwest Atlantic. These will be matched to records available from NAFO. Processes like this will be used to obtain better estimates of unreported and illegal fishing activities.

Discussion

Our approach is ambitious and relies upon considerable skilled collaboration. However, the need for the best, most complete records of total catch (=mortality estimates) and fishing effort is critical for the rational re-examination of fisheries policies in the light of historical stock collapses and current concerns. The collection of basic catch and fishing effort statistics is expensive and requires local knowledge to overcome errors in coding and interpretation. The role of consultants familiar with the fisheries in question is important to addressing any shortcomings in the official datasets and, particularly for inshore, artisanal, or recreational fisheries. Their data will be matched to records available from NAFO and other agencies.

Doubtless, mistakes were made when the official datasets were compiled but these are almost inevitable, and pale in comparison to deliberate omissions caused by functional or jurisdictional limitations. By functional limitations we mean that the data (at least in a usable form) do not exist, so it cannot be reported (because of the limited resources available). An example of this is illegal fishing; since estimates of such catches are not often made, they cannot be reported. In contrast, where data available, such as estimates of discarding, it may not be within the mandate of the reporting agency to include them in official catches. This is understandable as the need to report the value of landed catch underlay the genesis of most the world's fisheries statistical systems and this purpose still dominates all others. Jurisdictional boundaries, for example between tiers of government, may make the production of a comprehensive database, one that accounts for all sources of fishing mortality at all life-history stages, very difficult. Our Canadian case study from the Northwest Atlantic demonstrates that it is possible to make estimates of discarding for even non-commercial species if observer programs are in place. This would be very difficult based on the scaling of reported commercial landings alone. The estimates we have reported here can be improved through the use of general linear models or similar approaches that would allow estimates of blocks of time and space where no observer data exists. Using these methods it may also be possible to make estimates of discards for years when the observer program did not operate.

Our estimates confirm that discarding was not a minor phenomenon for vessels operating on Canada's Scotian Shelf (Table 8). Mortality estimates for many species would be significantly increased if discarding were included. Even so our estimate is acknowledged to be a minimum, especially for target species where we may have significant 'observer' effects. Our total of 10,569t of discards includes fishes, crustaceans, and marine mammals. Overall, however, the overall discard rate was only 4.9% (total discards/total landings). There was discarding of major target species such as cod and silver hake. We believe that the discarding estimates for non-target (generally non-quota) species are a minimal estimate. However, it is very likely that observer presence has caused estimates of the discarding rate of target species to be greatly underestimated. These results are, however, only for a small portion of the total North Atlantic fishing grounds and for only one year. Moreover, only the groundfish trawl fishery was examined here. Nevertheless estimating discarding rates of target and non-target species, even in light of these problems, will be required before total catch estimates can be attributed to ecosystems and nations' EEZs (see Pitcher and Watson, 2000).

Alverson et al. (1994) estimated that there were nearly 686,000t per year discarded in the Northwest Atlantic alone, but unlike our estimate, these did not include marine mammals. Based on our minimal estimates, discards in this region, based on the groundfish fishery alone, would have exceeded 120,000t for 1997. To reach the total of discards estimated by Alverson et al. (1994) for this region, our overall discarding rate would have to be nearer 30% than the 4.9% we calculated for the groundfish fisheries in statistical area 4VW in 1986. Likewise, estimates of discarding for species never landed would be very difficult to include without an observer programme. Nevertheless, individual estimates of discarding rates for the Northwest Atlantic groundfish trawl fisheries ranged from one in the top twenty of those fisheries with the highest "recorded" discard ratios, to four estimates in the lowest ten overall. The highest estimate was 5.28 to 1 (i.e. more than 5 kg of discards for each kg of target species landed). Of the several Northwest Atlantic fisheries listed, including the Hake Trawl, Cod Trawl, Redfish Trawl, and Plaice Trawl, all but the last had ratios below 10% (Alverson et at. 1994). The values reported in Alverson (1994) do not represent overall discarding rates but are simply the available individual estimates (pers. comm. D. L. Alverson). With 5.8% discarding by weight, the Northwest Atlantic Cod Trawl fishery had discarding rates comparable to those we calculated from observer data.

In addition to changes in the abundance and size structure of these species, changes to fishing policy, gear configuration, and fishing practise can greatly alter the numbers discarded. Rational discussion of fisheries policy, and its impacts, requires a reliable time series of discarding estimates. We have shown one example of how estimates of discards can be made with existing data sources. In 'data-poor' fisheries, we must rely on estimates from similar fisheries or our knowledge of the marine community that is likely to be impacted. In many cases the marine community will already have been highly altered – fortunately these changes also can be anticipated.

Changes to government policy in many countries of the world, whether mandated by international agreements or otherwise, have meant that estimates of bycatch and discarding are more available and are now discussed openly when stock management (for the major species) is considered. Illegal catches, on the other hand, are still taken as an admission of mismanagement, enforcement failure, or industry malfeasance, and are usually not included in official figures. In the cases where these estimates must be made and included in discussions, such as in international assessments of major commercial species, care is taken not be too specific as to which country's vessels have taken the catch and where it was taken. Unfortunately not all species currently have even this level of candid analysis. We are in the process of obtaining estimates of illegal and unmandated catch for the major North Atlantic fisheries but results are slow in coming as networks of trust are established. The need to include estimates of these catches is not yet universally accepted.

It is a well-accepted axiom, that first we must find out what is happening before we can plan to do anything about it. So it is also with marine policy. Transparent improvements to catch and effort data series will improve the quality of the debate and contribute to the sustained development that the majority of countries have already adopted as national policy

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APPENDIX 1: MARINE MAMMALS

Marine mammal catches are not recorded in a central database at DFO as happens for fish and invertebrates. The majority of seal hunting activity is aimed at harp and hood seals. The grey seal was the object of a bounty hunt from 1967 to 1984. The catches of other species of seals were aggregated as "other seal". The principal task was to obtain the data from different sources by contacting researchers working on one or several species. Second, the catch information that was available was the number of animals in the catch by age groups. The grouping differs depending on the hunting grounds and the species. In order to convert the catch in number to yield, the mean body weight for each broad size category was derived from growth curves in the best cases, and from more general data on adult sizes in other cases. Additional sources of removals, largely unaccounted for, are the animals wounded or killed but never recovered ("struck and lost" in seal hunt terminology), and are included in the catch statistics. Research has been undertaken to estimate the number of harp seals it represents (G. Stenson, pers. comm.).

Table 9. Weight for each commercial category for Harp seal.

Stage	Age	Weight (kg)	Rationale
pups	15 – 30 days	30	Stewart and Lavigne 1980; Sergeant, 1991 p.27
adult	ages 5-10 most likely assume sex ratio 50%	57-84	Based on catch at age data and Gompertz growth equation (April weight)

Reconstructing Harp Seal Catch

Data sources

Harp seal are the most abundant catch of marine mammals in western Atlantic Canada. Since harp and hooded seals are migrating from the Gulf of St. Lawrence and Newfoundland to Baffin Bay, southeastern Greenland and Hudson Strait, the catch of both Canadian and Greenland waters should be considered as sources of mortality on the same population. The Joint ICES/NAFO Working Group on harp and hood seals considers catches from West Greenland and half of Southeast Greenland derived from the Northwest Atlantic harp seal stock (Anon., 1998). Effort data for Norwegian and Russian hunting directed on West Greenland Ice were obtained from Appendix IV of the ICES document (Anon., 1999). Catch at age for the years 1952-1998 for each region, Gulf, eastern Arctic, and Greenland, were obtained from (Stenson et al., 1999). Catches for years 1950-1951 were obtained from ICNAF (1970).

Catch biomass

The harp seal catches are now recorded in two size categories, pups and 1+. Pup weight was obtained from Sergeant, 1991 (his Table 8). Mean weight of the catch was obtained by using the catch-at-age data for years 1952 to 1998 (Stenson et al. 1999) and the weight at age W_a computed from a Gompertz curve (Hammil and Stenson, in press).

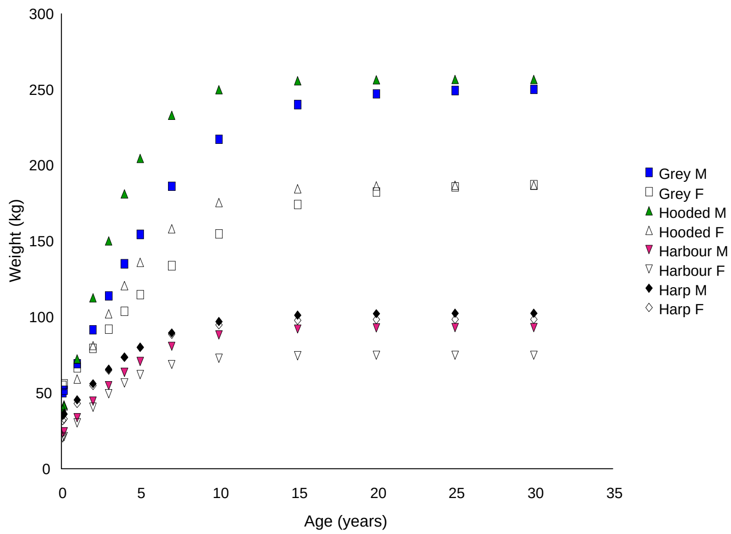

Figure 3. Weight at age relationship for Canadian seal species.

$$Biomass_y = Catch_{pup,y} * W_{pup} + \Sigma\, rop_{a,y} * W_a * Catch_y$$

where $prop_{a,y}$ is the estimated age composition of the yearly catch ($Catch_y$), expressed in percentages. The age composition for years 1950-1951 was assumed to similar to that of the year 1952. The Gompertz curve (Figure 3) was computed from specimens examined in April when seals are leaner than in the winter (Sergeant, 1991). The resulting mean weight of adult seals varied from 57 to 84 kg over the years (Table 8). Pup weight was estimated at 30 kg where seals are 15 to 30 days old. The hunting period varies within Canadian regions but the error in taking the April weight is probably smaller than error in the estimation of the catch at age (G. Stenson, DFO, St. John's Newfoundland, pers. comm.).