GIS/Spatial Analyses in Fishery and Aquatic Sciences
Watson - Spatial allocation of global fisheries landings using rule-based procedures (381-390)

Spatial allocation of global fisheries landings using rule-based procedures

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Abstract

Examination of the effects of fishing on marine ecosystems requires historical catch data on appropriate spatial scales. Most commercial fishing data are only currently available in the form of landings data that do not delineate the marine area from which the catch was extracted. Even when statistics are available by defined spatial areas such as the statistical areas used by the Food and Agriculture Organization (FAO) of the United Nations rather than by port landings, these reporting areas are often much larger in extent than the areas defined as ecosystems by most current ecological models and are difficult to use without modification.

A rule-based spatial allocation procedure was employed using a Microsoft Visual Basic application called 'SimMap' that has the ability to create and decompose ArcView shapefiles. An ESRI plug-in (Map Objects Lite) was used to provide the ability to show shapefiles created dynamically as a result of the catch allocation process. By creating Access databases describing the distribution of some 1500 commercial fisheries taxa, as well as the plethora of fishing access arrangements that nations have with other nations, we were able to create procedures for spatially allocating broader fisheries catch statistics into a global system of 30-min latitude x 30-min longitude spatial cells.

This paper presents the FAO catch data allocated to our global system of spatial cells for the year 2000. This sample output is indicative of the results achievable through the SimMap program, which has previously been used to demonstrate the impacts of fishing on the marine ecosystems of the North and South Atlantic, including biomass and trophic levels, to calculate direct overlaps of fisheries with populations of marine mammals, and to illustrate the spatial distributions of catch values and energy consumption by fishing fleets. Using the SimMap program, anomalies in official fisheries landings reported by countries to the FAO have been detected and have led to revised global statistics and historical trajectories.

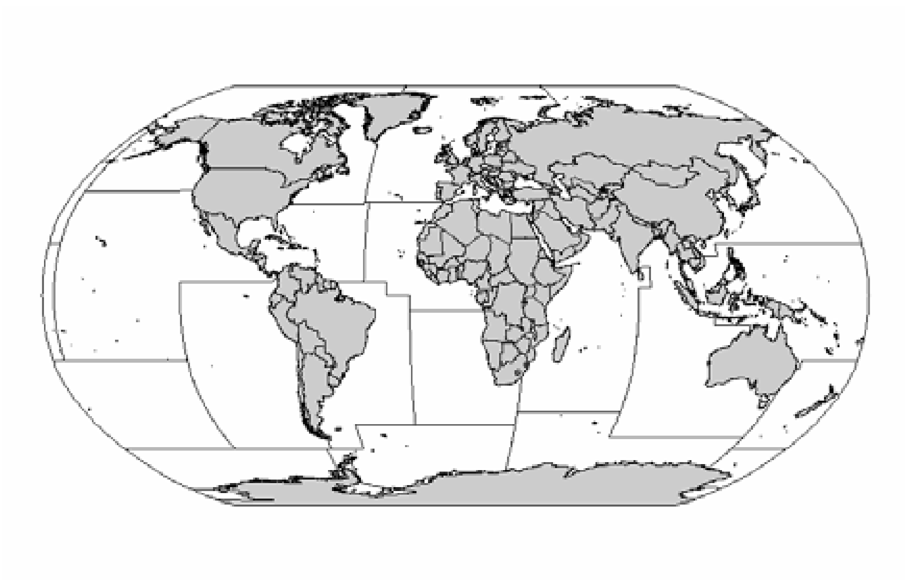
Key words

ecosystem, fisheries catch allocation, GIS, landings, marine fisheries.

1. Introduction

Mapping of fisheries catches is required for fisheries management and for studies that model changes in marine ecosystems resulting from fishing. Many countries have detailed fisheries reporting systems but these vary greatly in their precision and completeness. Global fisheries statistics, however, are available from relatively few sources, and one of these is the Food and Agriculture Organization (FAO) of the United Nations (FAO, 2000), which records landings by large statistical areas. Some parts of the world (East Central and South-east Atlantic, Black Sea and the Mediterranean) are reported by a system of smaller statistical sub-areas, which greatly reduces the size of the reporting areas. Unfortunately this does not include most of the world, and moreover, these smaller areas have only been in use since 1970.

Construction of ecosystem and other spatial models requires catch data that are georeferenced to a much finer precision than that typically provided by data sources such as those from FAO. The aerial extent of these models is usually in the 100s to 1000s of km^2, whereas the statistical reporting areas can exceed 10 million km^2 (Map 1). With data aggregated by such large regions, it is not possible to accurately prorate the landings data simply by any ordinary aerial method, in order to estimate the catches assumed to come from the small areas represented by most spatial models. Moreover, observer data are not available that could be used to georeference more than a very small fraction of the reported catches. Fortunately, another approach is now available, which involves a variety of tools incorporated in a Visual Basic program called SimMap (Watson *et al*., 2001).



Map 1. Major statistical areas used by FAO for reporting fisheries landings.

SimMap allows users to access a variety of databases such as global catches, and process these data into a finer spatial resolution based on other databases such as the distribution of the world's commercial marine fauna, global fishing access arrangements etc. Using rule-based processes, the program allocates the catch to relatively fine-scale maps that can be visualized via an ESRI plug-in (MapObjects Lite) or converted to shapefiles for use in other GIS programs.

The process of catch allocation is possible because of the information that is provided with the landing records by FAO. These include the taxonomic identity of the animals being fished, the country reporting the catch, the year of the catch, and the location of the broad FAO statistical reporting area. It is possible to use information about the biological distribution of the reported taxa (including preferred depth distribution), as well as the fishing access of the reporting country (in the year for which the catch was reported), to delimit and even prioritize finer-scale regions of the potential catch area within the statistical areas being cited. Comprehensive databases, which describe the global distribution of all commercial marine taxa, and also the areas of agreed and/or observed fishing access by functional taxonomic group for each fishing nation and for every year since 1950, were prepared. Using SimMap, landing information was used in conjunction with these auxiliary databases to convert large-scale records of landings, such as those from FAO, to grid-like maps of catches for each taxon, country and fishing year.

Through this process, which relies on spatial cells measuring a half-degree of latitude and longitude as the basic unit, it was possible to make landing data useable for a variety of further analyses.

2. Material and Methods

For each reported landing statistic, in addition to the weight of the landings, other information is usually available and our methods rely on using it. For example, this information usually includes: the reporting year, the taxonomic identity of the product landed, the country reporting the catch, and the statistical area from which the product was taken. Each of these pieces of information supplies clues as to the specific area of the sea from which the catches were likely taken. The procedures used by the SimMap program can be viewed as the process of 'deciding', on the basis of the constraints provided by these data, specifically where the catches could not have come from, as opposed to the whole of the large statistical reporting area that serves as our starting point.

All species of marine fish, crustaceans and molluscs were included in our analysis. Holothurians, horseshoe crabs, plants, corals, sponges, reptiles, and mammals were excluded. For the most part we accepted that the catches were likely taken from within the geographical confines of the statistical reporting area indicated by the landing record. But we have more valuable information to work with. We know the taxon or specific identity of the organism being described. Sometimes this is defined with precision, but it can be described in vague terms such as 'miscellaneous fishes'. Nevertheless, knowing the specific or broader identity of an organism allows us to use information on its distribution to eliminate parts of the potential catch area, or at least decide which parts of the potential catch area are the most likely source of the observed catches. For many marine organisms, some information is available. FishBase (Froese and Pauly, 2000), for example, provides information as to the depth and latitudinal ranges, and the habitat requirements of most fishes (commercial or otherwise). Similar information can be gathered for commercial non-fish species (see e.g. *www.cephbase.org*) and a range of other public sources. The basis for the species distributions used in this work is documented(*). Notably, it is usually possible to at least know whether a specific commercial organism has ever been reported from a particular FAO statistical reporting area. Our project has compiled such a comprehensive database, and this is used in the process of prorating catches reported as landing statistics to a system of rectangular spatial

(*) http://seaaroundus.org/distribution/search.aspx

cells measuring 30 min of longitude x 30 min of latitude (nearly 260 000 are needed to cover the earth).

The process of transforming statistical landings data into catch by spatial cells will be referred to as ‘allocation’ (Figure 1). Catch will only be allocated to cells where the organism has been found (otherwise the catch’s taxonomic description or the organism’s distribution are in error). This usually means that of the many spatial cells within an FAO statistical area (typically thousands), not all could have been the origin of the catch being reported, and of the possible cells some are more likely to have produced more of the catch based on their depth, latitude etc. That is, some cells are near the limits of the range of the organism and others, more optimal, are in the middle. More optimal cells, in terms of latitude depth, proximity to coral reefs (whatever it appropriate to the species) receive proportionately more of the reporting landing statistic. Distributions used for species can be viewed(**).

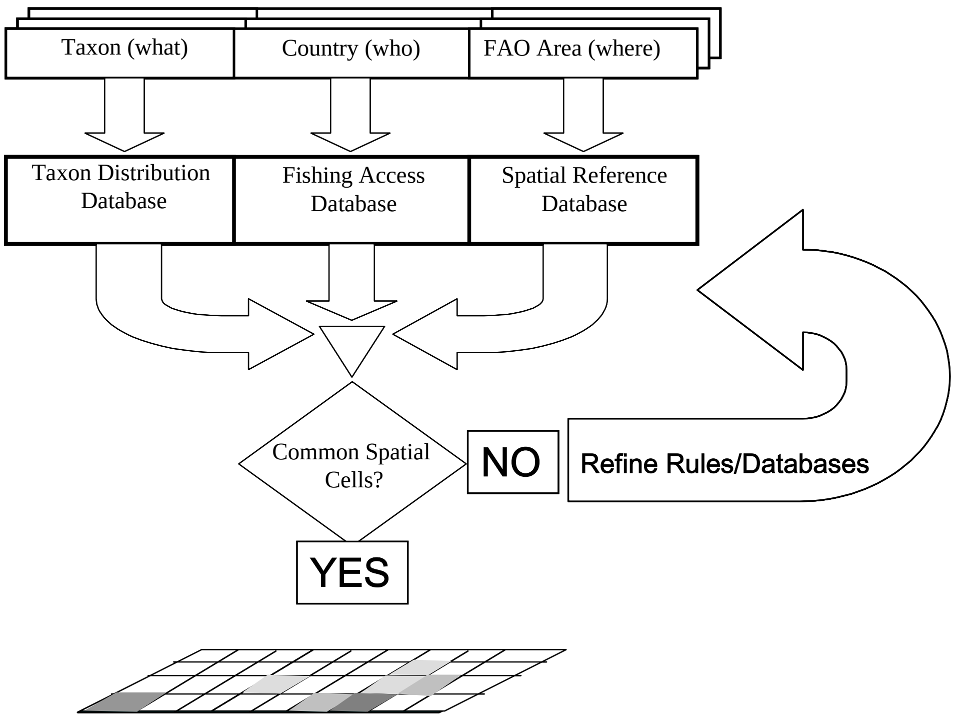


Figure 1. Allocation of fisheries landings statistics to spatial cells within the SimMap program.

(**) http://www.saup.fisheries.ubc.ca/saupmap/distribution/search.aspx

Of those cells that remain as a possible origin for the catch, some will be in areas where the reporting country was not allowed or was not known to fish that year (at least for that organism). Our comprehensive database of fishing access includes records of fishing agreements that build on the FARISIS database assembled by FAO (1999), as well as information from many published accounts. It takes note of the year when the exclusive economic zones (EEZ) were declared, but more importantly we have estimates of when they were put into effect. This is an important factor when deciding on the origin of catch as most of the world's marine landings are taken in coastal waters, which now lie within the boundaries of the EEZs of coastal states. Many countries allow other nations to fish under agreements, but some reserve these rights for their own nations' fishing fleets. Most agreements place restrictions on access, often limiting catches to a group of species, or to a type of fishing method. Illegal access is known to have occurred in some coastal areas in some years. All of this information is important when deciding on the origin of commercial catches.

Combining the distribution of marine taxa with information on the fishing access by a country restricts the potential spatial origin of catches in any one year to a subset of spatial cells defined for the world's oceans. If there is no overlap between the area for which the catch was reported, the range of the taxa's distribution, and the area of fishing access, then the reported landings record, the databases or the rules applied are in error. Through the development of this process we have made significant improvements to our databases such that approximately 99.7% of landings (by weight) can be allocated to spatial cells. Records have been discovered that appear in error and these have been sent back for review by the organizations that manage the landing records.

Allocation of the FAO landing records produces an extensive database consisting of approximately 200 000 files describing the catch rate for each of the global spatial cells for each reported taxa-country combination for each of the 51 reporting years (1950 to 2000 inclusive). Each of these can be viewed as a map describing the global catch. Catch rates rather than catches are mapped as the area of spatial cells changes with latitude. Linking this data with other information such as the trophic level of taxa, or their ex-vessel price, or even whether they are the food of marine mammals (Kaschner *et al*., 2001) allows considerable additional analysis to be performed.

3. Results

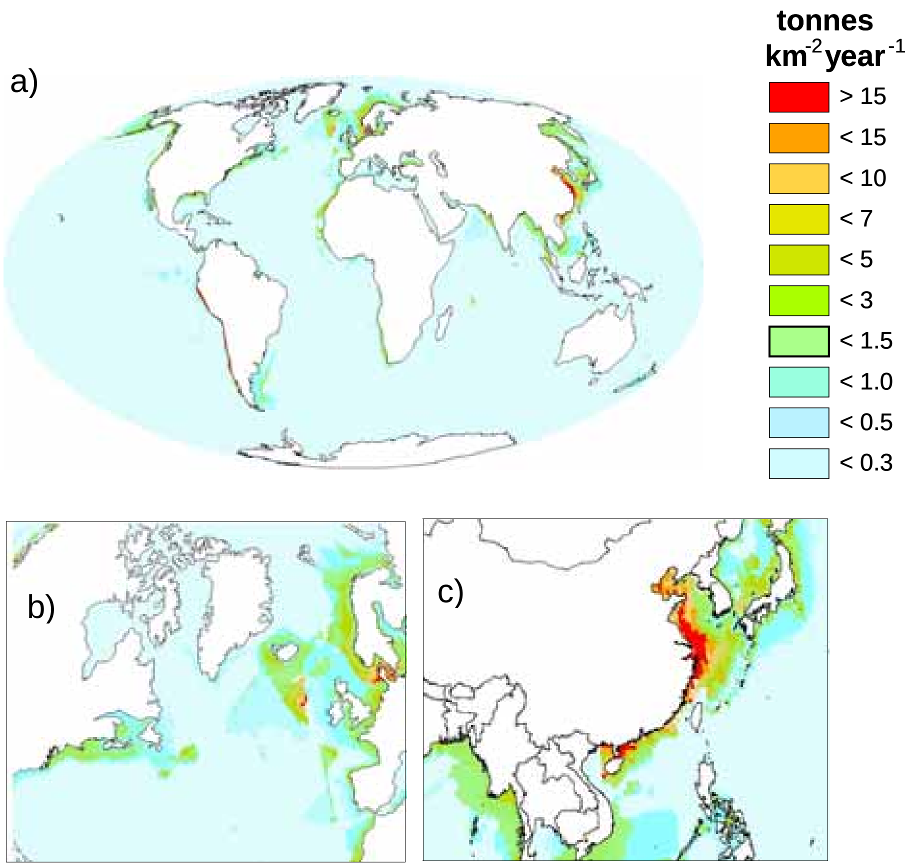
After FAO landing records have been allocated to a global system of spatial cells it is possible to produce maps that show the catch rate of any taxonomic group and any country for any year from 1950 to the present. Included here is a sample showing the catch rates for the year 2000 for all countries and marine taxa combined. In Map 2a it is possible to see at a glance where the highest catch rates were achieved globally for 2000. These include areas of the North Sea, the upwelling area along the Peruvian and Chilean coasts, as well as coastal areas of the East China Sea. All of these areas had catch rates that exceeded 15 tonnes km^{-2} $year^{-1}$. Over much of the world's oceans, however, catch rates are much lower and do not usually exceed 0.3 tonnes km^{-2} $year^{-1}$.

A close up of the North Atlantic reveals the structure of catch rates in detail (Map 2b). Since the collapse of the cod fisheries in Atlantic Canada, catch rates in this region have not matched those from parts of the North Sea. Large areas have low catch rates, including the coastal areas to the northwest where ice prevents fishing for most of the year.

Along the coast of China, the use of SimMap revealed very high reported catches. These were examined by Watson and Pauly (2001) who found that they resulted, at least partially, from systematic over-reporting (Map 2c). The models of expected catches that were required to reveal this phenomenon would not have been possible without the catch allocation procedures available through the SimMap program and its supporting databases.

4. Discussion

The maps presented here represent preliminary findings based on our catch allocation process used in the SimMap program. The results were based on FAO data but did not use sub-area data, which have been available since 1970 for parts of the world. Nevertheless, they demonstrate the power of the allocation process to resolve large-scale landings data to fine-scale catch maps. In our desire to improve our representation of global catches, over time we will substitute other data sources for some regions such as those from the International Council for the Exploration of the Sea (ICES) and the Northwest Atlantic Fisheries Organization (NAFO) for the North Atlantic region. These will enrich the global maps by providing smaller, more tightly defined statistical areas with which to begin the allocation process. It will also be possible to begin a more rigorous validation process. Although more than 99.7% of allocated catches are in accordance with rules imposed by known distribution and fishing arrangements, they may still prove to be in error at smaller scales when compared to detailed data from national logbook systems.



Map 2. Allocated catch rates (tonnes km^{-2} year $^{-1}$) for all species for 2000 based on FAO's data (a) globally, (b) for the North Atlantic, and (c) for Southeast Asia.

The process described here has already supported efforts to extend individual spatial models using Ecospace (Walters *et al*., 1999) of the North Atlantic to an analysis of biomass changes in the entire ocean basin, revealing dangerous declines in biomass of higher-trophic-level species (Christensen *et al*., 2003). Catch maps such as presented here support work investigating changes to fisheries on a global scale, including changes in the trophic levels of landings indicating generalized degradation (Pauly *et al*. 1998; 2002). Analysis of mapped catches prepared by SimMap has confirmed that, contrary to widely published statistics, the global total marine landings has been declining for many years, masked by systematic over-reporting (Watson, 2001; Watson and Pauly, 2001).

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