2. PART II

SPATIAL ALLOCATION OF FISHERIES LANDINGS FROM FAO STATISTICAL AREAS 61 AND 71

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2.1 Summary and conclusions

The fisheries landing statistics of FAO statistical areas 61 and 71 for the 1990s were examined using a rule-based procedure. A large part of landings from these areas were reported by the People's Republic of China, and much of this was identified as 'miscellaneous' fishes, crustaceans or molluscs. These statistics were disaggregated into lower taxonomic groups, based on landings reported by China and two of its nearest neighbors. The disaggregated landing reports for each statistical area were then allocated to 30-minute by 30-minute spatial cells based on spatial databases of known taxon distributions and national fishing access. The former database was compiled, in consultation with experts, based on ocean depth, primary productivity, coral reef presence, and other factors. The later database included considerations of global maritime boundaries, fishing access arrangements and permanent ice cover. Each landing record was accumulated proportionally in each of the ocean's spatial cells, producing maps of global landings for a number of marine groups. Landing records for which there was no spatial cells common between the reporting FAO statistical area, the distribution for the taxon reported, and the reporting nation's fishing access rights were logged, and used to identify reporting problems.

A general additive model was used to examine the relationship between the spatially disaggregated landing records and major oceanographic factors. Landing rates within spatial cells were predicted by the log of cells' average depth and primary productivity. The predicted landing rates were compared to those based on landings reported to FAO. Maps of the reported, predicted, and differences in landing rates are included, and these demonstrate that some locations within FAO 61 and 71, in particular the coast of China, have reported landings which are not consistent with the global model. Specifically, there were large areas within the Chinese EEZ with landing rates of 10 t km^{-2} year^{-1} or higher than those predicted by the model. Possible explanations for the predicted differences in landing rates and landings are discussed. The most likely explanation is gross over-reporting of landings within area 61 by China.

2.2 Introduction

Official statistics of fisheries landings are provided to FAO annually by member countries. These are reported for a range of species and aggregated taxa for each of FAO's statistical areas. There has been concern for several years that some reports provided for statistical areas 61 and 71 have indicated levels of fish landings that are not consistent with global patterns (Pang and Pauly, this volume). Despite differences in fleet size and fishing intensity, it is now widely held that the majority of the world's fisheries are taking most of the sustainable production of marine ecosystems, and this production is related through the food webs to underlying factors controlling primary production (Pauly and Christensen 1995). It therefore seems unlikely that some regions can produce considerably higher fisheries landings than comparable areas elsewhere regardless of the magnitude of fishing fleets employed.

Investigation of likely landing levels requires fisheries statistics on finer spatial and taxonomic scales than typically reported to FAO. It is common for reporting countries to break down the major portion of their statistics to the genus or species level of identification. This level of description is highly desirable if knowledge of the fish's distribution and habitat requirements is to aid the spatial disaggregation of statistics. Unfortunately, some countries provide the majority of their fisheries statistics by highly aggregated categories such as 'miscellaneous marine fishes'.

A two-stage process is therefore required. The first is to disaggregate the reported statistics into taxa of lower levels, such as families, genus or species. This process allows to proceed with the second stage, wherein aspects of the fish's biology and known distribution are combined with what is known of the reporting country's access to fishing areas to produce a fine-scale spatial disaggregation of the reported landings. This process builds global maps of annual landing rates as each country's landing records are processed. Using these maps, statistical models relating landing rates to known oceanographic parameters such as depth and primary productivity allow anomalies to be identified.

Highly anomalous landings rates can then be reviewed with reporting nations for clarification.

2.3 Methods

2.3.1. Spatial Resolution and Spatial Cell Size

The process described in this report seeks to disaggregate landings from FAO's statistical areas to smaller units that can be used in a statistical model using oceanographic parameters. To facilitate this, spatial units of ½ degree latitude by ½ degree longitude were used. These will be referred to as 'spatial cells'. The choice of this size was a balance between larger cells that would average many depths and other characteristics, and provide only a crude model of distribution, and a finer structure that would require intensive computing power and data of a scale not widely available. Over the world's seas and oceans the selected cell size requires a matrix with approximately 180,000 cells.

2.3.2. Data Sources

2.3.2.1. Fisheries Landings

The fisheries data used was supplied by FAO. For all but annual tuna and billfish landings FAO's FishStat+ (www.fao.org/fi/statist/FISOFT/FISHPLUS.asp) was consulted. Landings of tuna and billfish were taken from FAO's Atlas of Tuna and Billfish Statistics (http://www.fao.org/fi/atlas/tunabill/english/home.htm). The totals were used unaltered. A process of taxa disaggregation (described below) was used, however, to enable the use of published distributional and biological information in the spatial disaggregation process. Only records of fishes and marine invertebrates were used in the analysis, i.e., data on marine mammals and algae were not considered. The statistical data used were only 'official' reported landings, i.e., they do not include discarding, nor do they make any attempt to correct for unreported, misreported catches or other errors.

2.3.2.2. Fish Taxonomy, Biology and Distribution

FishBase (www.fishbase.org) provided excellent information on fish taxonomy, their biology and distribution. This provided a framework for our databases and assisted with the process of spatial disaggregation by providing actual distributions or information on the limits to the distribution of many fish taxa. SpeciesDAB (Coppolla et al. 1994, and see below) supplied similar information for many invertebrate taxa.

2.3.2.3. Depth

Sea-floor elevations data were taken from the ETOPO5 dataset available on the U.S. National Geophysical Data Center's 'Global Relief' CD (www.ngdc.noaa.gov/products/ngdc_products.html) that provides elevation in 5-minute intervals for all points on earth. Elevations below sea level (depths) were averaged for each spatial cell used in our database.

2.3.2.4. Primary Productivity

Global primary productivity data (in g C m^{-2} $year^{-1}$) were provided by the Joint Research Centre (JRC), of the European Commission Space Applications Institute (SAI) Marine Environment Unit (ME), in Ispra, Italy. (See www.me.sai.jrc.it/me-website/contents/shared_utilities/frames/index_windows.htm). The data set was developed using the Behrenfeld and Falkowski (1997) model, which includes (US) NOAA's satellite data on sea temperatures, chlorophyll *a* levels and light irradiance. The data set was available on a spatial scale of approximately 0.176 degree and was averaged into ½ degree spatial cells. The time period averaged was for readings taken during 1999, and was taken to represent a basic climatology of primary productivity.

2.3.2.5. Coral Reefs

Global modeled data (from Kleypas et al. 1999) on the presence or absence of coral reefs was made available from Reefbase (www.reefbase.org/) on a 5-minute resolution. This was accumulated into our ½ degree spatial cells to provide a spatial reef coverage index, used to disaggregate landings of species whose life-history requires the presence of coral reefs.

2.3.2.6. Seamounts

The gazetteer provided on the U.S. National Geophysical Data Center's 'Global Relief' CD (www.ngdc.noaa.gov/products/ngdc_products.html) was used to count the number of known seamounts in each of our ½ degree global spatial cells. These were used to provide the basis for the distribution of taxa known to occur only on, or in the proximity of seamounts.

2.3.2.7. Permanent Ice Coverage

Data from the U.S. National Snow and Ice Data Centre, Boulder, Colorado (nsidc.org/index.html) were obtained which provided monthly limits of sea ice coverage. These were used to identify spatial cells unavailable for fishing due to (nearly) permanent ice coverage.

2.3.2.8. Exclusive Economic Zone

Boundaries of exclusive economic zones (EEZ) and declared fishing zones for fishing nations were taken from the Global Maritime Boundaries CD, which uses existing claims and the United Nations' Law of the Sea's rules to delineate these zones even though many are still technically or legally unresolved (Veridian, 2000; www.maritimeboundaries.com/main.htm).

2.3.2.9. Fishing Agreements

A database of fisheries agreements between nations, FARISIS (FAO, 1998) was kindly made available by FAO. The utility of the information therein was enhanced by importing it to Microsoft Access database, a process that required parsing the exported text file using a Microsoft Visual Basic program. This database allows the fishing agreements between nations to be listed so that the rules of fishing access required in the spatial disaggregation process could reflect current or historical arrangements.

2.3.3. Taxonomic Disaggregation

Taxonomically highly aggregated landings statistics are problematic for any analysis including spatial modeling. Some countries report the majority of their landings under the 'miscellaneous marine fishes', 'miscellaneous marine crustaceans' and 'miscellaneous marine molluscs' categories (Table 8). Some of these countries combine a large, highly aggregated catch fraction with large reported landings. China tops the list of these countries in term in the total tonnage it reports in this format. According to FAO statistics China has reported approximately 113 million tons of marine landings this way since 1950, nearly three times as much as any other nation.

Because statistics supplied by China to FAO contribute such a large part of the landings reported from areas 61 and 71 (34% since 1990), it was necessary to disaggregate these landings based on the more detailed records from neighboring areas, presumed to have similar catch compositions). Taiwan and South Korea (T&SK) were used for this; North Korea (i.e., the Democratic Peoples' Republic of Korea) was not, as it provides even less taxonomic detail than China (Table 8).

Disaggregation of landing records was performed separately for each broad category (fishes, crustaceans and others, mainly molluscs). Within each category the percent of the total landings that was assigned to the 'miscellaneous' category was assigned to more specific taxa based on the breakdown of landings reported by T&SK. This procedure was performed independently for each statistical reporting year.

For example, in 1998 China reported 27% of its total landings as 'miscellaneous marine fishes'. This same year, the average proportion of total landings reported by T&SK for the same group of aggregated taxa was only 10%. Therefore, initially the procedure assigned 17% (the difference) of the Chinese 'miscellaneous marine fish' landing statistics to fish taxa identified at more specific levels than as 'miscellaneous' in the Chinese statistics or in those of T&SK. This difference was assigned step-wise in small fractions using a rule-based approach. The rules were that:

- China's proportion of landings assigned to any identified taxon can never be reduced, regardless of what T&SK reported;
- The fraction of the difference remaining being assigned to a taxon during each iteration was in proportion to the difference between the proportion reported by China and that reported by T&SK;
- All taxonomic levels were considered equally, i.e., fish families were treated the same as fish genera or species; and
- All taxa reported by T&SK could be used for reporting Chinese landings even if a taxon was not specifically reported in official Chinese landings statistics (but could be presumed to be a hidden portion of the 'miscellaneous' category).

In our example, this process continued until the additional 17% of 'miscellaneous' fish fraction reported by China but not by T&SK was assigned to explicit fish taxa.

Once this first stage was completed, the remaining proportion of Chinese landings still identified as 'miscellaneous marine fishes' were

Table 8. Countries reporting landings in taxonomically highly aggregated groups based on totals from FAO statistics from 1950 to 1998 inclusive. Listed are the top 20 countries (or territories) ranked by the total tonnage (million t) reported as 'miscellaneous marine fishes', 'miscellaneous marine crustaceans' or 'miscellaneous marine molluscs' (all abbreviated as MM). The overall mean over the same period is also shown.

Country	Marine Total (million t)	MM Fishes (million t)	MM Crustacea (million t)	MM Molluscs (million t)	MM Fishes (%)	MM Crustacea (%)	MM Molluscs (%)	MM Total (%)	MM Total (million t)
China	200.0	74.4	16.5	22.2	37.2	8.2	11.1	56.6	113.1
Korea D.P.R.	36.1	35.4	0.3	0.0	98.1	0.7	0.0	98.8	35.7
Thailand	68.2	32.2	0.0	0.1	47.2	0.0	0.2	47.3	32.3
Japan	375.2	21.6	0.3	0.0	5.8	0.1	0.0	5.8	21.9
Viet Nam	24.0	19.1	0.0	0.6	79.5	0.0	2.6	82.1	19.7
Myanmar	18.3	18.1	0.0	0.0	98.9	0.0	0.0	98.9	18.1
Indonesia	64.1	10.3	0.1	0.0	16.0	0.1	0.0	16.1	10.3
Former USSR	209.9	8.1	0.1	0.6	3.9	0.1	0.3	4.2	8.8
India	67.5	7.7	0.6	0.1	11.5	0.8	0.1	12.4	8.4
Malaysia	26.1	7.7	0.2	0.0	29.3	0.7	0.1	30.0	7.9
Mexico	31.2	6.6	0.0	0.1	21.0	0.0	0.2	21.2	6.6
Korea Rep.	68.0	5.7	0.0	0.3	8.4	0.0	0.4	8.9	6.1
Bangladesh	6.3	4.4	0.3	0.0	69.6	4.1	0.0	73.7	4.6
Brazil	21.9	4.3	0.0	0.2	19.6	0.1	0.7	20.4	4.5
Taiwan	29.5	4.2	0.0	0.1	14.1	0.0	0.3	14.4	4.3
Spain	56.0	3.4	0.2	0.2	6.0	0.3	0.4	6.7	3.8
Italy	16.9	3.0	0.1	0.3	18.0	0.8	2.0	20.8	3.5
USA	171.0	3.3	0.0	0.2	1.9	0.0	0.1	2.0	3.4
Iran	4.0	3.0	0.0	0.0	75.6	0.0	0.3	76.0	3.0
Hong Kong	6.4	2.4	0.0	0.1	37.5	0.0	2.0	39.5	2.5
MEAN	-	-	-	-	19.6	0.3	0.3	20.3	1.2

assigned to explicit fish taxa within the Chinese statistics in proportion to their presence at that stage. Thus, all fish landings were assigned to taxa more informative than the 'miscellaneous' segment.

The same procedure was used for crustaceans, and for all remaining unidentified fractions (mostly molluscs). Note that this procedure did not alter, for any year, the overall total landings for China, nor the total for each broad category (fishes, crustaceans, and others); also note that the 'taxonomically disaggregated' landing records resulting from this procedure were used only for the spatial disaggregation detailed below, not to generate alternative landing statistics for China.

2.3.4. Taxa Distribution

The process of spatial disaggregation of fisheries statistics required a database of the global distribution of all taxa reported to FAO. For each taxon, the proportion of the world's known distribution was mapped to the spatial cells represented in the database. This information is provided in two ways.

The first and preferred method was to use maps of distributions prepared by experts. Many excellent texts such as Muus and Dahlstrøm (1974), Scarratt (1982) and Cohen et al. (1990) provide global distributional maps that augment the extensive set of distributions available from FAO (Anon, 2001). Some were provided to us as geographical information systems (GIS) compatible files. Most distributions, however, were available only as photocopies and had to be scanned, re-projected and otherwise processed before they could be added to our database. Most sources produce distributional maps using knowledge of fisheries landings, museum collections and generalized depth and temperature ranges of the exploitable ages and life history stages. What is here referred to here as 'depth' is the depth of water over which the species can be taken rather than the depth in the water column the species is taken from. The reason for this is to allow generalizations using a global bathymetry. This definition means that there are no depth limits for taxa such as 'large pelagic fishes', as these species may be found over the deepest parts of the world's oceans. If depth limits for a taxon were these were used in conjunction with distributional maps to restrict the distribution to a subset of the ocean's spatial cells when the spatial database record was created. Thus, individual spatial cells included in broad distributional areas on maps were not included if they were outside the known depth range for the taxa.

The database describing the distribution of marine taxa is not simply presence/absence for each spatial cell but rather the proportion of the world's distribution to be found in that cell. Moreover, it was assumed that areas of the world that had a greater general primary productivity level would on average support greater populations of most marine fauna. Thus, the spatial primary productivity data mentioned above were used to apportion the distribution of each taxon among the cells that fell within its distributional limits.

Other methods were used when distributional maps were not available. The first was used exclusively for taxa identified at the genus level, which were assumed to cover the sum of all areas covered by their component species, as available in our database. When no such distributions were available, tabular limits to distribution (for depth, and/or latitude and FAO Statistical Area) were used, as for other taxonomic levels. One excellent source for the required tabular data (i.e., information on the biology and distribution of fishes) is FishBase (Froese and Pauly 2000), which includes contributions from numerous experts, and which covers the world ocean. FAO's SPECIESDAB (Coppola et al., 1994) is also an excellent source of tabular information on range of fishes and marine invertebrates, notably their presence/absence in the 18 marine FAO statistical areas.

When tabular limits were used to construct distributions, the maximum and minimum depths were used as more than absolute limits: based on numerous published information (see e.g., Alverson et al. 1964, Pauly and Chua 1994), it was assumed that the maximum abundance occurred at depths approximately 1/3 of the way between the minimum and maximum depths, and a triangular distribution was used to construct the proportions of the distribution found at each intervening depth. In a similar way the maximum distribution of taxa with latitudinal limits was taken to occur at a midpoint in the range with a triangular distribution assumed.

These tentative distributional ranges, based on known depth or latitude limits were reviewed when presence/absence by FAO statistical data was available. That is, if a species had a wide distribution described by a range of depths and latitudes but was never known to occur in FAO statistical area 21 then its distribution in our database would reflect this known limit, and spatial cells within FAO 21 were removed from its range.

Therefore, the limits of the final distribution of taxa for which maps were did not previously exist reflect depth, latitude, and presence/absence by FAO statistical area, while the relative abundance with these limits reflect depth, latitudinal range, and primary productivity. A number of experts have reviewed these distributions, and where appropriated, their input was used to adjust the parameters underlying questionable distributions.

2.3.5. Fishing Access

Each of the ocean's spatial cells was assigned to a country if the center of that cell occurred within the boundaries of the EEZ of that country, as defined by the Global Maritime Boundaries database (Veridan, 2000). Cell that were not assigned to any country's EEZ were considered to be on the high seas, and accessible by fleets of all countries.

Rules were developed to allow fishing access to the EEZ cells of one country by another. Initially only the country itself was allowed to access the cells assigned to its own EEZ and this was modified as more information became available on that country's fishing practices and access rights. 'Guilds' of fishing countries were defined, based on the assumption of mutual access to the EEZ cells of any country within the guild by another country in the guild. Such arrangement (albeit with many specific limitations) exists between fishing vessels of the European Union and elsewhere. There are also many examples where countries with historical ties (former colonies or territories) allow fishing access to another countries. On a case-by-case basis, in consultation with national experts, the database of fishing access that is used in the spatial disaggregation process was extended by granting 'permission' to allow access to the spatial cells defining the EEZ of one country by other countries.

The fishing access database was further enhanced by consulting with the FAO's FARISIS database (FAO 1998), which records fishing agreements and allows non-historical and distant-water fishing access rights to be included.

2.3.6. Spatial Disaggregation

Using landing records that were taxonomically disaggregated where necessary, a rule-based process was used to spatially disaggregate the landings statistics from their original FAO large statistical areas to a subset of much smaller spatial cells within that area (Fig. 5).

The official landings records for all countries fishing within the reporting year as determined by FAO statistics (A in Fig. 5) are processed as a set of database records by first disaggregating the statistics for large generalized group into records at lower taxonomic levels (B in Fig. 5 – described above). These records were then processed individually though the spatial disaggregation process (C in Fig. 5, detailed in Fig. 6).

Each taxon represented in a landings record was looked up in the database of taxonomic spatial distributions (produced by the methods described above). This yielded a subset of the spatial cells of the worlds oceans and the proportion of the world's distribution that had been estimated for each cell. The country reporting (fishing) is used with the database of fishing access (described above) which records which spatial cells are available for that country to fish in (including the EEZ of other countries for which arrangements exist). The FAO area that the statistic is reported for was used to provide a third set of spatial cells, i.e., those within the statistical area from which a landing was reported. These sets of spatial cells are then compared and if there is no overlapping cells the landing is not allocated and an 'error report' is logged (Fig. 6). Otherwise, the reported landing is assigned among overlapping cells in proportion to their areas. Thus, landing rates (t km^{-2} $year^{-1}$) are accumulated in each cell as each record is processed.

Logging allocation errors has proven very instructive in reviewing whether species distributions and countries' fishing access ranges were consistent with landings records. Indeed, this process allows for constant improvement of the underlying databases. At present, there are approximately 5% of global landings that cannot be mapped to a set of spatial cells for lack of overlap between the distribution of the various taxa, the reporting countries' fishing access, and the FAO statistical area from which the landing was reported. Some of these errors will be eliminated when access arrangements for fishing countries and taxa distributions have been fully reviewed by experts. This process has already required a shift from predominately depth-determined species distributions, which do not always allow landings in statistical areas where they are frequently reported (often these problems have been confirmed by experts on the fisheries in question). Sometimes errors originate

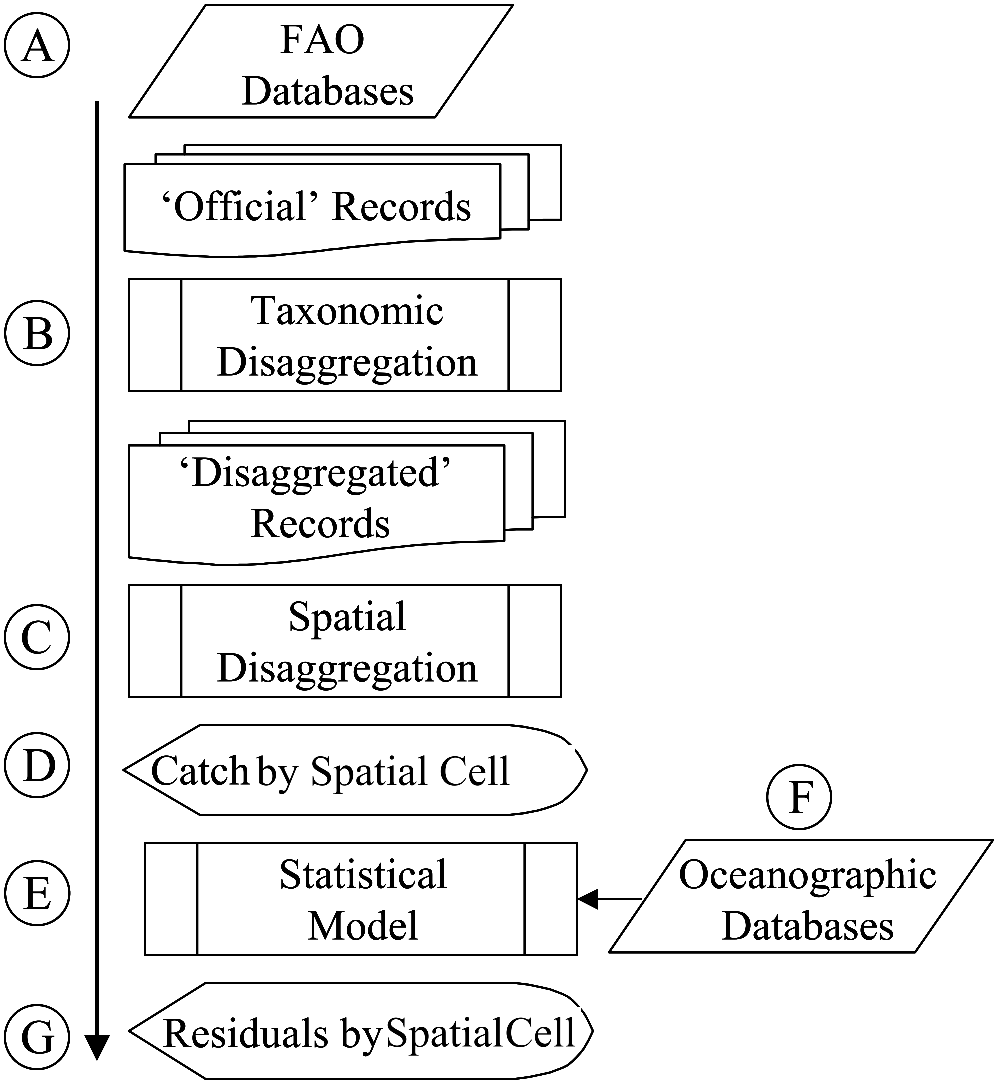

Figure 5. Schematic diagram of the processing procedures used to produce landing rate maps.

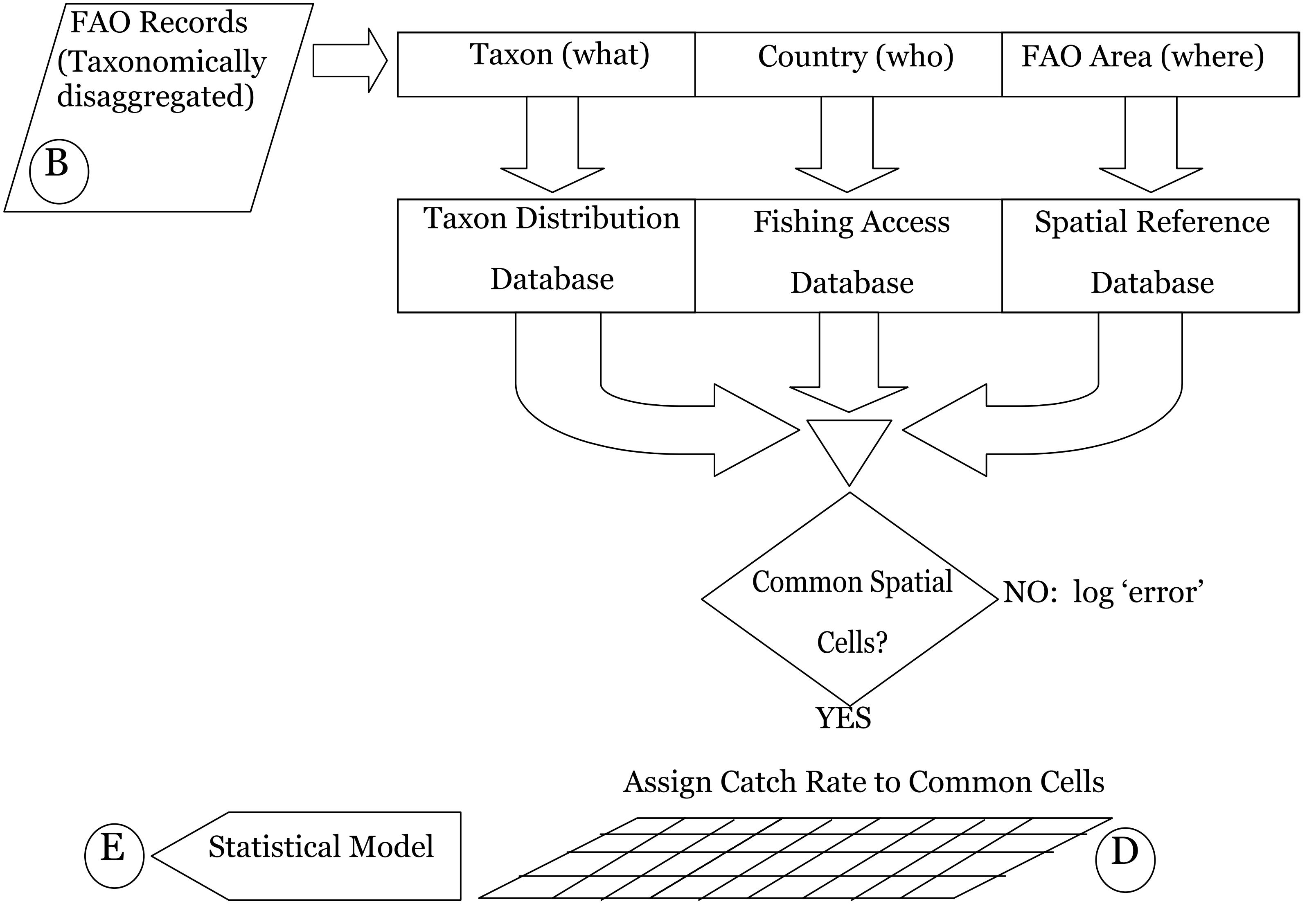

Figure 6. Schematic diagram of the spatial disaggregation process.

because countries do not report landings for all FAO areas they fish in, but simply report all the landings for their major fishing areas, or report distant-water landings from closer fishing areas. In the case of China, reports to FAO do not attribute catches to statistical areas. FAO staff must attribute what catch they can to areas outside of statistical area 61 (within which China's EEZ is located) and assign the rest by default to area 61.

Still, we have achieved overlap (between the species' distribution, the countries' fishing access, and the FAO area the landings were reported from) for about 95% of the world's marine landings, with each of our spatial cells allocated a proportion of these landings depending of their area (cells nearer the poles are smaller than those on the equator). In this way, a grid map of landing rates is build up as each landing record is processed (D in Fig. 6). Though each record is processed for the taxonomic level it is reported at (after disaggregation), the results are gathered and reported in 12 major groups for the purposes of this contribution. These groups are: anchovies, herrings (defined as non-anchovy Clupeiformes), perches (taxa in Perciformes), tuna and billfish, cods, salmons/smelts, flatfishes, scorpionfishes (Scorpaeniformes), sharks and rays, crustaceans, molluscs, and 'others'. This report only deals with the aggregate total of these 12 groups.

2.3.7. Statistical Analysis

The result of the spatial disaggregation was a database for each year providing the landing rate (t km^{-2} year^{-1}) of each of 12 major groups of marine organisms for each of the global spatial cells (including the total of all groups combined). This database was merged with databases of oceanographic factors such as average depth and primary productivity so that a statistical model describing the distribution of annual landing rates could be developed (E in Fig. 5). Annual landing distributions for 1990 to 1998 were averaged, and this dataset representative of the 1990s was used in subsequent modeling and mapping.

A general additive model (GAM) was developed using the S-Plus 2000 software by examining which oceanographic factors best predicted the pattern of global landings rates produced by the spatial disaggregation process (E in Fig. 5). A range of factors and their interactive terms were considered. After examining the model fits and the patterns of residuals, a simple model relating landing rate, C (t km^{-2} year^{-1}) to primary productivity rate, p (g C m^{-2} year^{-1}), and the log of average depth, $\log(d)$ (m), and their interaction, i was chosen:

$$C \approx p + \log(d) + i \qquad \text{... 2)}$$

2.3.8. Landing Rate Predictions

A statistical model was used to predict the average 1990s landing rates for all reporting groups combined, for each spatial cell, given its primary productivity and depth. Predicted landing rates were truncated at zero (necessary for some cells in low productivity oceanic areas). The cells' predicted landings were expressed as a proportion of the sum of global landings, and multiplied by the reported total of annual landings. This rescaling produced predicted landing rates for each spatial cell with the same average global total of landings as reported for the period, i.e., it corrected for 95%, rather than 100% of the global catch having been spatially disaggregated. Thus, the GAM was not used explicitly to predict global landings from oceanographic parameters, but rather the distribution of landing rates amongst the spatial cells contributing to the reported total landings. The difference in the landing rates resulting from the spatial disaggregation of current statistics and the rescaled predictions based on primary productivity and average depth were mapped. Predicted changes to the landings of statistical areas 61 and 71 were calculated by using the landing rates that the GAM predicted for cells in these areas.

2.4. Results

2.4.1. Taxonomic Disaggregation

The results of the taxonomic disaggregation are shown in Table 9. The example shown is for an average of the 1990s, for which the Chinese landings reported to FAO averaged 53% reported only to the three major 'miscellaneous' groups, 7% identified to family and 39% identified to the species or genus level. After the disaggregation there were no landings left in the miscellaneous category, 2% at the order or class level, 9% at the family and 89% identified to species or genus. The large increase in the latter category allowed specific biological and distributional information to be used to greatly increase the precision of the subsequent spatial disaggregation process.

Table 9. Mean reported landings for China for the 1990s, broken down by for each taxon (at the level of description supplied to FAO) with the proportion of the total. The proportional breakdown for China's neighbours, Taiwan and South Korea, is shown for comparison and because it was used in the taxonomic disaggregation that resulted in the column labeled 'Adj. proportion China'. Taxa with zero reported landings were left blank (Group 1=finfish; Group 2=crustaceans; Group 3=molluscs).

Group	Taxa	English Name	Proportion China	Proportion Neighbours	Adj. proportion China
1	-	Miscellaneous marine fishes	34.81	8.68	-
1	*Trichiurus lepturus*	Largehead hairtail	8.73	4.54	8.73
1	*Engraulis japonicus*	Japanese anchovy	5.09	9.76	8.63
1	*Decapterus*	Scad	4.92	0.62	4.92
1	*Scomber japonicus*	Chub mackerel	3.34	10.32	8.46
1	Polynemidae	Threadfins	2.83	-	2.83
1	*Scomberomorus niphonius*	Japanese Spanish mackerel	2.62	1.18	2.62
1	*Cantherhines*	Filefishes	2.53	0.05	2.53
1	Stromateidae	Butterfishes	1.63	0.53	1.63
1	*Theragra chalcogramma*	Alaska Pollack	1.39	10.95	8.42
1	*Larimichthys polyactis*	Yellow croaker	1.23	1.40	1.59
1	*Muraenesox cinereus*	Daggertooth pike conger	1.02	0.35	1.04
1	*Nemipterus virgatus*	Golden threadfin bream	0.87	0.30	1.04
1	*Sardinops melanostictus*	Japanese pilchard	0.77	1.65	1.53
1	Sparidae	Porgies	0.65	0.48	0.65
1	Mugilidae	Grey mullets	0.64	-	0.64
1	*Pseudosciaena crosea*	Large yellow croaker	0.54	0.85	0.82
1	*Ilisha elongata*	Elongate ilisha	0.45	0.02	0.45
1	*Epinephelus spp.*	Groupers	0.25	0.11	0.25
1	Sciaenidae	Drums or croakers	0.11	3.07	2.34
1	Scombridae	Mackerels, tunas, bonitos	0.08	0.09	0.10
1	*Clupea pallasii*	Pacific herring	0.05	0.34	0.26
1	Elasmobranchii	Sharks and rays	-	0.38	0.30
1	Rajiformes	Skates and rays	-	0.37	0.28
1	Clupeiformes	Herrings	-	0.28	0.22
1	Salmoniformes	Salmons, pikes and smelts	-	0.05	0.04
1	Pleuronectiformes	Flatfishes	-	0.01	0.01
1	Ariidae	Sea catfishes	-	0.01	0.01
1	Lophiidae	Goosefishes	-	0.33	0.25
1	Exocoetidae	Flyingfishes	-	0.04	0.03
1	Scorpaenidae	Scorpionfishes or rockfishes	-	0.26	0.20
1	Serranidae	Sea basses: groupers and fairy basslets	-	0.03	0.02

Group	Taxa	English Name	Proportion China	Proportion Neighbours	Adj. proportion China
1	Sillaginidae	Smelt-whitings	-	0.06	0.04
1	Malacanthidae	Tilefishes	-	0.05	0.04
1	Lutjanidae	Snappers	-	0.19	0.15
1	Mullidae	Goatfishes	-	0.00	0.00
1	Gobiidae	Gobies	-	0.11	0.08
1	Istiophoridae	Billfishes	-	0.00	0.00
1	Cynoglossidae	Tonguefishes	-	0.10	0.08
1	*Sphyraena*	Barracudas	-	0.04	0.03
1	*Caranx*	Jacks	-	0.42	0.32
1	*Scomberomorus*	Spanish mackerels	-	0.09	0.07
1	*Seriola*	Amberjacks	-	0.23	0.16
1	*Upeneus*	Mullets	-	0.02	0.02
1	*Auxis*	Goatfishes	-	0.14	0.10
1	*Coryphaena hippurus*	Common dolphinfish	-	0.45	0.34
1	*Istiophorus platypterus*	Indo-Pacific sailfish	-	0.12	0.09
1	*Chanos chanos*	Milkfish	-	0.00	0.00
1	*Acanthocybium solandri*	Wahoo	-	-	-
1	*Euthynnus affinis*	Kawakawa	-	0.08	0.06
1	*Katsuwonus pelamis*	Skipjack tuna	-	0.18	0.14
1	*Scomberomorus commerson*	Narrow-barred Spanish mackerel	-	0.17	0.13
1	*Scomberomorus guttatus*	Indo-Pacific king mackerel	-	0.05	0.04
1	*Thunnus alalunga*	Albacore	-	0.56	0.43
1	*Thunnus albacares*	Yellowfin tuna	-	0.73	0.60
1	*Thunnus obesus*	Bigeye tuna	-	0.06	0.05
1	*Thunnus thynnus thynnus*	Northern bluefin tuna	-	0.03	0.02
1	*Thunnus tonggol*	Longtail tuna	-	0.59	0.47
1	*Makaira indica*	Black marlin	-	0.04	0.03
1	*Makaira mazara*	Indo-Pacific blue marlin	-	0.15	0.11
1	*Tetrapturus audax*	Striped marlin	-	0.02	0.01
1	*Xiphias gladius*	Swordfish	-	0.04	0.03
1	*Conger myriaster*	Western North Pacific conger	-	0.95	0.73
1	*Cololabis saira*	Pacific saury	-	2.56	1.93
1	*Hyporhamphus sajori*	Japanese halfbeak	-	0.07	0.05
1	*Gadus macrocephalus*	Pacific cod	-	0.19	0.14
1	*Eleutheronema tetradactylum*	Fourfinger threadfin	-	0.29	0.22
1	*Lates calcarifer*	Barramundi	-	0.00	0.00
1	*Priacanthus macracanthus*	Red bigeye	-	0.22	0.16
1	*Trachurus japonicus*	Japanese jack mackerel	-	1.19	0.89

Group	Taxa	English Name	Proportion China	Proportion Neighbours	Adj. proportion China
1	*Decapterus russelli*	Indian scad	-	0.19	0.13
1	*Megalaspis cordyla*	Torpedo scad	-	0.04	0.03
1	*Mene maculata*	Moonfish	-	0.19	0.15
1	*Nibea mitsukurii*	Nibe croaker	-	0.09	0.07
1	*Pennahia argentata*	Silver croaker	-	0.31	0.23
1	*Arctoscopus japonicus*	Sailfin sandfish	-	0.13	0.10
1	*Hypoptychus dybowskii*	Korean sandeel	-	0.37	0.28
1	*Pampus argenteus*	Silver pomfret	-	0.54	0.42
1	*Psenopsis anomala*	Melon seed	-	0.33	0.25
1	*Sebastes alutus*	Pacific ocean perch	-	0.00	0.00
1	*Chelidonichthys kumu*	Bluefin gurnard	-	0.00	0.00
1	*Pleurogrammus azonus*	Okhostk atka mackerel	-	0.21	0.16
1	*Stephanolepis cirrhifer*	Thread-sail filefish	-	1.80	1.36
1	*Mugil cephalus*	Flathead mullet	-	0.29	0.22
1	*Atrobucca nibe*	Longfin kob	-	0.05	0.04
1	*Platycephalus indicus*	Bartail flathead	-	0.15	0.11
1	*Ruvettus pretiosus*	Oilfish	-	0.17	0.13
1	*Saurida undosquamis*	Brushtooth lizardfish	-	0.01	0.01
1	*Paralichthys olivaceus*	Bastard halibut	-	0.10	0.07
1	*Etrumeus teres*	Round herring	-	0.08	0.06
1	*Spratelloides gracilis*	Silverstriped round herring	-	0.03	0.02
1	*Sardinella zunasi*	Japanese sardinella	-	0.49	0.37
1	*Clupanodon thrissa*	Chinese gizzard shad	-	0.40	0.29
1	*Decapterus maruadsi*	Japanese scad	-	0.27	0.19
1	*Parastromateus niger*	Black pomfret	-	0.18	0.13
1	*Rachycentron canadum*	Cobia	-	0.03	0.02
1	*Lateolabrax japonicus*	Japanese seaperch	-	0.07	0.05
1	*Chirocentrus dorab*	Dorab wolf-herring	-	0.00	0.00
1	*Pagrus auratus*	Squirefish	-	0.11	0.08
1	*Saurida tumbil*	Greater lizardfish	-	0.25	0.19
1	*Acanthopagrus schlegeli*	Black porgy	-	0.01	0.01
1	*Pseudopleuronectes herzensteini*	Littlemouth flounder	-	0.71	0.52
1	*Takifugu porphyreus*	Purple puffer	-	0.32	0.24
2	-	Miscellaneous marine crustaceans	7.93	0.00	-
2	*Acetes japonicus*	Akiami paste shrimp	3.56	0.92	4.36
2	*Portunus trituberculatus*	Gazami crab	2.12	0.76	2.57
2	*Trachypenaeus curvirostris*	Southern rough shrimp	1.47	0.11	1.79
2	*Penaeus chinensis*	Fleshy prawn	0.49	0.06	0.59

Group	Taxa	English Name	Proportion China	Proportion Neighbours	Adj. proportion China
2	*Portunus pelagicus*	Blue swimming crab	0.27	0.10	0.33
2	Decapoda	Decapoda	-	2.07	2.55
2	Brachyura	Marine crabs nei	-	2.34	2.88
2	*Paralithodes*	King crabs	-	0.00	0.00
2	*Metapenaeus*	*Metapenaeus* shrimps nei	-	0.06	0.07
2	*Penaeus monodon*	Giant tiger prawn	-	0.01	0.01
2	*Scylla serrata*	Indo-Pacific swamp crab	-	0.02	0.03
2	*Penaeus japonicus*	Kuruma prawn	-	0.21	0.26
2	*Panulirus longipes*	Longlegged spiny lobster	-	0.00	0.00
2	*Penaeus penicillatus*	Redtail prawn	-	0.13	0.16
2	*Metapenaeus joyneri*	Shiba shrimp	-	0.19	0.24
3	-	Miscellaneous marine molluscs	10.38	0.48	-
3	Sepiidae, Sepiolidae	Cuttlefish,bobtail squids nei	1.50	0.76	1.53
3	*Strongylocentrotus*	Sea urchins nei	0.00	0.00	0.00
3	-	Sea-urchins and other echinoderms	-	0.15	0.09
3	Cephalopoda	Cephalopods nei	-	0.12	0.08
3	Bivalvia	Clams nei	-	1.16	0.73
3	Gastropoda	Gastropods nei	-	0.24	0.15
3	Octopodidae	Octopuses, etc. nei	-	0.78	0.48
3	Mytilidae	Sea mussels nei	-	0.25	0.16
3	Cardiidae	Cockles nei	-	0.18	0.11
3	*Loligo*	Common squids nei	-	0.83	0.52
3	*Haliotis*	Abalones nei	-	0.01	0.01
3	*Arca*	Ark clams nei	-	0.04	0.02
3	*Anadara granosa*	Blood cockle	-	0.11	0.07
3	*Mactra sachalinensis*	Hen clam	-	0.27	0.18
3	*Turbo cornutus*	Horned turban	-	0.33	0.21
3	*Ruditapes philippinarum*	Japanese carpet shell	-	0.73	0.46
3	*Todarodes pacificus*	Japanese flying squid	-	9.16	5.66
3	*Meretrix lusoria*	Japanese hard clam	-	0.12	0.07
3	*Stichopus japonicus*	Japanese sea cucumber	-	0.09	0.06
3	*Mytilus coruscus*	Korean mussel	-	0.17	0.11
3	*Crassostrea gigas*	Pacific cupped oyster	-	0.82	0.52
3	Loliginidae, Ommastrephidae	Various squids nei	-	1.05	0.67
3	*Pecten yessoensis*	Yesso scallop	-	0.01	0.00

2.4.2. Current Spatial Allocation

The taxonomic and spatial disaggregation produced landing rate estimates for each of the global spatial cells. These results showed large areas of the world's oceans with landing rates from 0 to 0.2 t km^{-2} year^{-1} (Fig. 7) and the global average including oceanic areas was 0.22 t km^{-2} year^{-1}. There were areas, however, primarily along the coast of China, where reported landing rates were in excess of 10 t km^{-2} year^{-1}. Though these unusually high landing rates were in areas of relatively high primary productivity, they were, nevertheless very unusual as they combined very high landing rates with an extensive area (approximately 367,500 km^{-2}). The area with the unusual landing rate was predominately within the EEZ of China (based on Pang and Pauly, this volume, our spatial disaggregation access rules assumed only China could fish in these areas). Therefore, these landing rates originated with landings statistics reported to FAO by China. Globally only 0.3% of the area of the world's oceans had landing rates higher than 10 t km^{-2} year^{-1}, and 30.6% of this area occurred within the EEZ of China. Other areas with high landing rates typically had exceptionally high primary production rates, such as along the Peruvian coast where permanent, strong upwelling plum support fisheries on species low in the food we mainly the anchoveta *Engraulis ringens* (Pauly et al. 1989; Faure and Cury 1998).

2.4.3. Predicted Spatial Allocation

Predicted landing rates for each spatial cell based on primary productivity and the log of average depth (assuming the same total of global landings as 'officially' reported) are mapped in Fig. 8. The most obvious difference between the landing rates in this figure and those in the map of the landing rates based on the spatial disaggregation process (Fig. 7) is the great reduction in the landing rates in the cells along the coast of China, with most this area having predicted landing rates of 2 to 5 t km^{-2} year^{-1}, much less than the many values of 10 t km^{-2} year^{-1} or greater implied by the reported landings.

2.4.4. Predicted Differences in Landing Rates and Landings

Mapping the difference in the landing rates of spatial cell resulting from the spatial disaggregation process and those predicted by the statistical model produced Fig. 9. Clearly there were many areas where the differences were quite small (2 t km^{-2} year^{-1} or less) and this would be expected as the total global landings were scaled to the same reported global total. Within statistical areas 61 and 71 there were a few locations such as along the Gulf of Carpentaria in northern Australia where a greater landing rate was predicted than was reported (based on spatial disaggregation).

There were, however, some more obvious differences in landing rates. The dominant feature of Fig. 9 is the large area, along the coast of China, where reductions in landing rate of 10 t km^{-2} year^{-1} or more were predicted by the GAM. Overall, only 0.16% of the area of the world's oceans was predicted to be over-reported to this extent, and of this, 19% was within the EEZ of China. This indicates that the landings predicted for China (which has its EEZ in this area) are much greater than would be predicted based on a global model of primary productivity and depth.

Using the landing rates predicted by the GAM, the average landings for the 1990s for areas 61 and 71 would be reduced by 48% to 8 and 6.8 million t respectively. The average annual Chinese landings for the 1990s in areas 61 and 71 would be reduced overall by 64% to 2.7 million t.

2.5. Discussion

The basis for the analysis presented here is to try and predict what fisheries landings and annual landing rates would be expected from areas of the world's oceans. The best predictive model found so far was one using underlying primary productivity and depth. Based on this there were significant areas where observed landing rates were very different from the predicted values.

It is widely accepted that reported landings usually underestimate the catch of marine species. In many fisheries there is significant discarding of catch before it is landed (Watson et al. 2000). In many circumstances, particularly where quotas exist, not all catch is declared. Catch may also be misidentified, or misreported from another statistical area. Methods exist to estimate these reporting problems (Pitcher and Watson, 2000). It is rare that there is concern that reported landings may overestimate actual landings.

The model reported here was developed to estimate the spatial distribution of catch rates globally, and not to estimate the actual landings made by any specific nation. The rescaling of model-predicted catch rates to the 'official' global

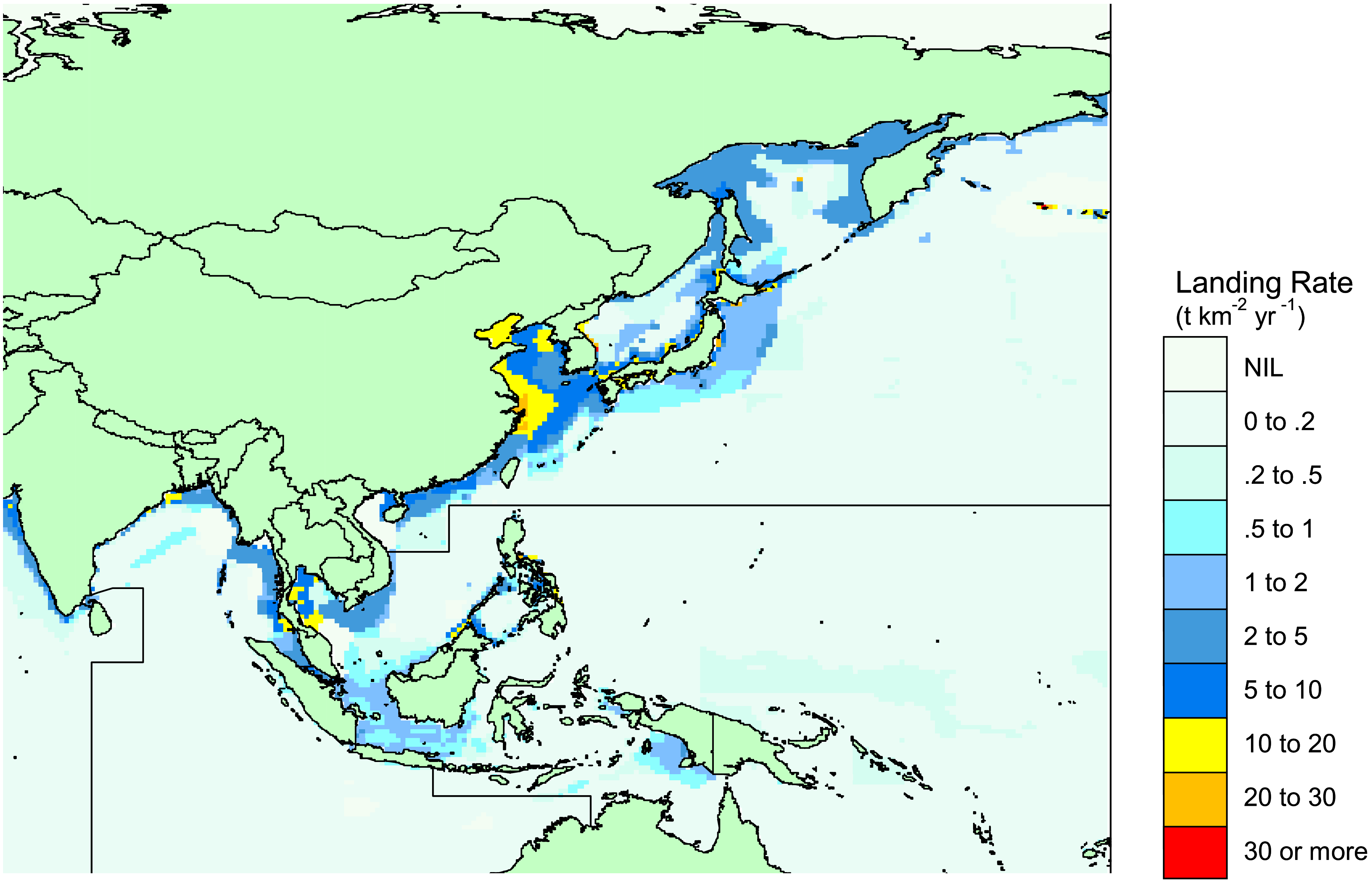

Figure 7. Map of reported mean landing rates in Northeast and Southeast Asia (t km^{-2}year^{-1}) of all species combined for the 1990s resulting from taxonomic and spatial disaggregation of FAO's fisheries landing records.

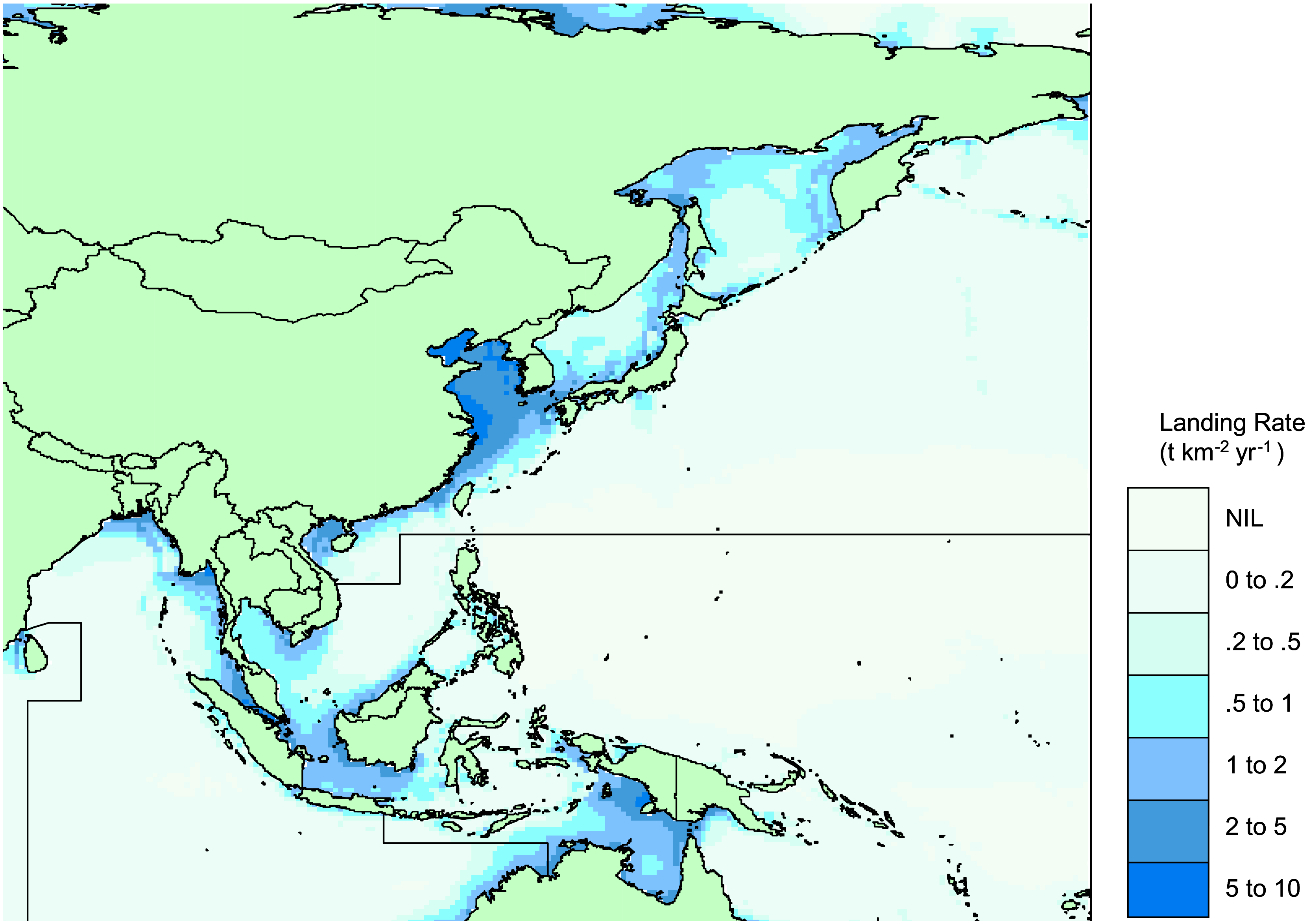

Figure 8. Map of mean landing rates in Northeast and Southeast Asia (t km^{-2}year^{-1}) of all species combined for the 1990s predicted by primary productivity and depth in a global general additive statistical model

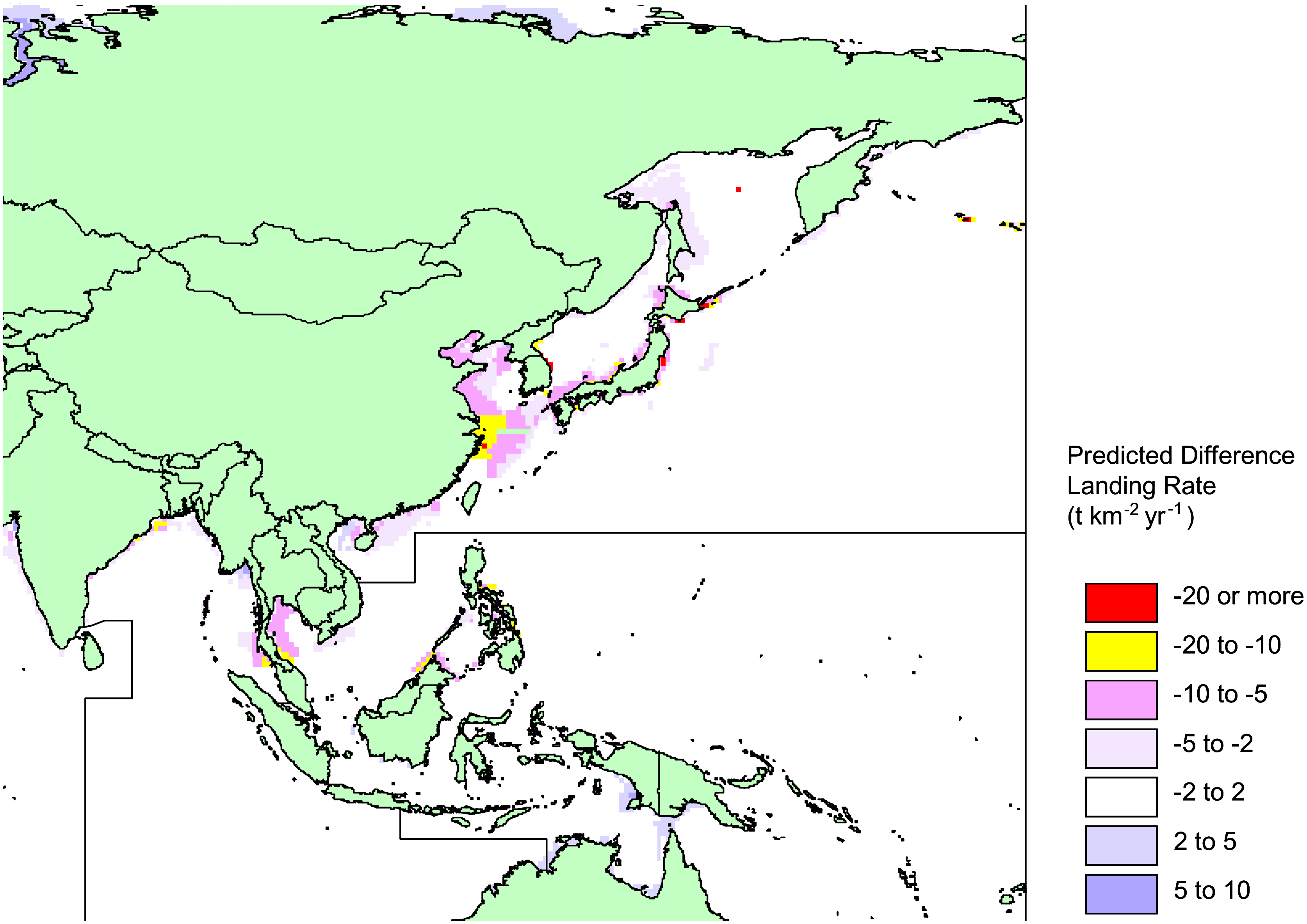

Figure 9. Map of mean predicted change in landing rates (t km^{-2}year^{-1}) of all species combined for the 1990s predicted by primary productivity and depth in a global general additive statistical model

total of landings precludes any accurate estimates of what a specific country's landings should actually be, as the actual global total may be considerably different than the total currently accepted (indications are that it is actually higher due to underreporting by many countries). This model does, however, clearly indicate that there are abnormally high catch rates reported for coastal China, originating from Chinese reported landings. Although this is not the only place in the world's oceans where this difference exists, it is the most extensive, and it dominates the statistics from FAO areas 61 and 71.

Regardless of exact predictions, the conclusion must be, therefore, that landings reported from coastal areas of China are much greater than would be predicted. If the underlying primary productivity of this area does not explain the high landing rates, then perhaps aspects of the Chinese fleet may suggest other reasons. Smith (1999) examined the global fleets of vessels over 100 tons and found that though the statistics for the Chinese fleet were somewhat problematic (China is not well represented in Lloyd's database), what evidence there was suggested a huge fleet: with substantial increases through the 1990s. There is, however, evidence that the majority of this huge fleet is of low horsepower and do not have the same fishing capacity of European vessels of the same size. Pang and Pauly (2001) also examined Chinese vessel statistics and found a large (though not well enumerated) fleet of relatively small tonnage vessels that were mostly suitable for coastal waters. Despite the unavailability of accurate statistics describing the Chinese fleet, it seems quite unlikely that the enhanced landing rates reported from this region could be explained by fleet capacity alone.

Another explanation for the unexpectedly high landings reported from Chinese waters in FAO statistical areas 61 and 71 may be the misreporting of landings made by distant-water fleets. Chinese distant-water fleets (DWF) were reported to fish as far away as Morocco but to discharge their catches at Chinese home ports (Bonfil et al., 1998). If these landings were reported from the statistical area of the home port (area 61) rather than from the area where the catch was taken, this would increase landings reported to area 61 (and similarly for area 71). In this way, fish landings supported by primary productivity in other areas of the world may account for the high landing figures reported. However, as shown by Pang and Pauly (this volume), the catches of Chinese DWF are not large enough to account for the large residuals of the GAM described above.

If greater fish catches are being taken from the Chinese coast than almost anywhere else in the world's oceans, through whatever means, it would suggest that these catches are not sustainable. In fact, Chen et al. (1997) found that several stocks in the East China Sea have declined significantly over the last 20 years. Aggregate levels of fisheries landings were sustained only through the increase in take of relatively newly fished and low value species. They suggested that presently, certain environmental conditions may be sustaining high fish catches for some stocks, but that without these conditions, these stocks may be endangered. The unusual apparent productivity of Chinese coastal waters is also not consistent with a global analysis performed by Caddy et al. (1998), who observed that while there had been a rise in global catches over the last decades, there had in fact been a slowing of growth or even decline in recent years (late 1990s). Pang and Pauly (2001) cite examples of declining stocks in Chinese coastal waters, without these declines being reflected in reported landings, which, from 1985 to 1998, invariably increased.

The continued high levels of Chinese landings seem very problematic given the failure of global statistical models to predict them based on well-founded factors such as primary productivity and depth. While global fisheries catches stagnates or declines in most areas, China's nominal catches increased, contributing 1.5 % per year more to the world catch since 1989, up to the present, staggering figure of 19 % of world's fisheries landings – this from an EEZ that includes only 1.4% of the world's shelf area. The most tenable hypothesis for this unusual trend is that for some time, reports of Chinese landings have overstated actual landings for these areas, as suggested by Pang and Pauly (this volume). Such inaccuracies can have serious consequences for China to manage its fisheries sector, and for international efforts to monitor the state of global fisheries.