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Global fishing effort (1950–2010): Trends, gaps, and implications

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ABSTRACT

According to a recent World Bank report, the intensification of global fishing effort and the ensuing depletion of marine fish stocks causes economic losses of 50 billion US dollars annually. Data deficiencies, however, currently hamper analysis of global fishing effort. We analyzed data from the Food and Agricultural Organization of the United Nations (FAO), the EUROPA fishing fleet registry, and peer-reviewed and other publications, to determine the global trends in fishing effort from 1950 to 2006. Our results show that global fishing effort, expressed as total engine power and the number of fishing days in a year (kilowatt days), was roughly constant from 1950 to 1970, and then steadily increased up to the present. Europe dominated global fishing effort, followed by Asia. Projecting current trends suggests that Asia will soon surpass Europe. Trawlers contribute a major fraction of global fishing effort, as do vessels greater than 100 gross registered tons. Current estimates of global fishing effort, the number of vessels, and total vessel tonnage are, however, underestimates given the data gaps that we have identified. Our results are useful in the following ways: (1) they may encourage researchers in academia and government to improve global fishing effort databases; (2) they allow deeper global analyses of the impact of fishing on marine ecosystems; (3) they induce caution in accepting current underestimates of economic losses of global fisheries; and (4) they reinforce calls for a reduction in global fishing effort.

1. Introduction

The world's marine fisheries resources are under enormous pressure, with global fishing effort estimated to exceed the optimum by a factor of three to four (Pauly et al., 2002). This excess fishing effort then contributes to economic losses estimated at 50 billion US dollars annually – the "sunken billions" (World Bank, 2009). Specifically, these losses (calculated based on an aggregate production model) are brought about by the combined effects of high and increasing fishing effort, declining fish stocks, stagnating or declining fish prices, and fisheries subsidies that support unprofitable fishing and overexploitation (World Bank, 2009; Sumaila et al., 2007).

FAO (2009) reported that in 2007, 52% of global fish stocks were fully exploited, 28% were overexploited or depleted, 20% were moderately exploited, and only 1% showed signs of recovery – all a direct consequence of the fishing effort expansion from the 1970s onwards. Effective fisheries management requires an understanding of fishing effort around the world. For many countries, however, fishing effort data are patchy, non-existent, or inaccessible. Thus, there is a need to evaluate existing fishing effort data (at the country level), understand the data trends, identify and fill data gaps, and suggest improvements in effort data archival. These are essential elements for improving global fisheries production models, reforming global fisheries (World Bank, 2009), and building a better global fishing vessel record system (FAO, 2010).

Fishing is an old and important human activity in many countries, where it contributes to the culture, economy, employment, and food supply of coastal communities (Gabriel et al., 2005; World Bank, 2009). Arguably, industrial fishing started in the 1880s, with the deployment of the first steam-powered trawlers around England, which heralded the first use of fossil fuel (coal) in fisheries. Subsequent technological improvements intensified fishing effort, which led, one and a quarter centuries later, to the huge vessels that ply the oceans, fishing at all depths and latitudes (Gabriel et al., 2005). Indeed, while major conflicts, such as the two world wars (WW), led to temporary effort reduction, they also contributed to the development of new technologies that increased the effectiveness of fishing effort. This is particularly true for WW2 (e.g., radar and echo-sounder), and the Cold War following shortly thereafter (e.g., side-scan sonar and GPS), although how and when fishing nations adopted and applied new fishing technologies is not well documented.

The increasing globalization and demands for fish products from a growing human population with higher incomes, and an insistent desire for seafood in developed countries (Swartz et al., 2010),

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all contribute to increasing global fishing effort. Many important questions remain however. These include: (1) how much fishing effort the world is exerting; (2) what level of fishing capacity is required; and (3) how long can the ocean continue to support current fishing effort. These are difficult questions because of the low quality of available data, and the ecological, economic, political, and social complexity of fisheries management (World Bank, 2009; Holt, 2009).

A wide variety of methods for measuring fishing effort have developed over time (see Appendix A). In the published literature, fishing effort is expressed in the following ways: (1) number of vessels (Dunn et al., 2009; Rodríguez-Quiroz et al., 2009); (2) size (or tonnage) of vessels (Bordalo-Machado, 2006; FAO, 2009; World Bank, 2009); (3) spatial and temporal intensity of fishing such as 'days at sea', 'hauls, tows, or trips per unit of space or time', etc. (Mangel et al., 2010); (4) dimension and characteristics of fishing gears such as number of hooks, number of pots, or total length of nets (Pons et al., 2010; Waddington and Meeuwig, 2009); (5) engine power (horsepower or kilowatt) (Bordalo-Machado, 2006; Mu et al., 2007; Yu and Yu, 2008); and (6) the use of advanced technological aids such as fish finders (Karakulak, 2004; Melvin et al., 2002) (Appendix B.1–3). Increasing skills of skippers and fishing crews also contribute to the effectiveness of fishing effort and capacity (Pascoe and Coglan, 2002; Squires and Kirkley, 1999). Considering such factors leads to differentiation between 'nominal effort', expressed in measures such as (1)–(5) and 'effective effort,' which considers (1)–(6) together. This theme, however, is beyond the scope of this paper due to the lack of available data (but see Section 3). Throughout this paper, we refer to fishing effort as the product of total engine power and number of fishing days in a year (kilowatt days), without consideration of fishers' skills or changes in technology, except for fishing gear types.

FAO (2009) presents only the total number of powered fishing vessels around the world, about 2.1 million, but does not give the total power exerted by these vessels. A recent study focused on European Union (EU) countries estimated that in recent years there was about 7 million kilowatts exerted annually by 13 of the EU member countries (Villasante, 2010). Regional and by-country analysis of fishing effort exists at various levels of detail (see Appendix A), but the global estimates of fishing effort and trends from 1950s to date are difficult to compare, for the reasons above. Part of the problem is that numerous countries fail to provide information to global inventories, such as the FAO's fishing fleet database (see Appendix C.1 and C.2). One region that is exemplary in their compliance is the EU, which has created and maintains a systematic and accessible fishing vessel registry for its member countries (see http://ec.europa.eu/fisheries/fleet/index.cfm).

The main objectives of this study are the following: (1) to organize and analyze global fishing effort data assembled from sources cited above; (2) to present and discuss the estimated temporal trends in fishing effort (expressed as kilowatt days) globally, by country, vessel tonnage class, and vessel/gear types; and (3) to identify the remaining knowledge gaps and propose improvements and future research directions. Our overall goal is to improve one crucial aspect of the World Bank (2009) aggregate fisheries production model – the fishing effort by country, though we do not attempt to update this model here.

2. Methods

2.1. Data

We used two databases and peer-reviewed and other publications to assemble and cross-validate estimates of global fishing effort. The main dataset was the FAO Fishing Fleet online database (FAO, 2010). This database contains the total number of fishing vessels, gross registered tonnage (GRT), and employed gears (1970–1995), by GRT class, with scattered information on fishing power, but includes most of FAO's data-contributing countries (161 countries, albeit with missing data for some years – see Appendix C.1 and C.2). This dataset was the basis for many of FAO's recent publications on the global fisheries (e.g., FAO, 2009; World Bank, 2009).

In addition, we used the EUROPA Fishing Fleet Register online database (http://ec.europa.eu/fisheries/fleet/index.cfm?method=Download.menu). This dataset provided us with comprehensive information on various characteristics of fishing vessels (e.g., length, gross tonnage, etc.) for EU member countries from 1990 to the present.

Moreover, we searched the Web of Science (WoS) for fishing effort publications using keywords such as 'Fishing Capacity', 'Fishing Effort', 'Fishing Gears' and 'Fishing Vessels' (see Appendix A). We identified over 1000 articles published from 2000 to 2010, which helped verify the fishing effort estimates from online databases. We present only the data between 2000 and 2010 because these recent papers mostly cited earlier available data, and because most of the earlier data were too patchy to be useful for our country-level validation purposes (see Appendix A).

2.2. Data processing

We derived our first estimates of global fishing effort by country, vessel GRT class, and vessel/gear types (excluding non-fishing vessels such as patrol, research vessels, mother-ships/carrier vessels etc.) from FAO (2009), supplemented by gap-filling procedures (see Appendix C.1 and C.2). These consisted of five steps:

1. standardizing the entries in the FAO online data e.g., we calculated gross tonnage when it was not provided using vessel characteristics relationships from the EUROPA data (see Appendix B.1–3) and we converted GRT, the main reported unit in the FAO database, to gross tonnage (GT) using a published GRT vs. GT relationship (http://www.iim.csic.es/pesquerias/Pesca/NAFO/SCDocs/2001/scr01-005.pdf). Overall, we ensured that our vessel/gear types and tonnage class categories followed the International Vessel/Gear Classification and Length/Tonnage categorization documented in FAO's "*Handbook of fishery statistical standards*," which is intended to cover the concepts, definitions, and related matters as applied to fishery statistics by the international agencies of the Coordinating Working Party on Fishery Statistics (www.fao.org/fishery/cwp/handbook/M/en);
2. using vessel gross tonnage and kilowatt relationships from the EUROPA online data we estimated the kilowatt power of the calculated vessel gross tonnage data in the FAO online dataset where no estimates existed (see Appendix B);
3. using the interpolation function in the '*t*-series package for R' to calculate, between 1970 and 1995, the values of missing annual estimates of fishing effort by country, vessel/gear types, and tonnage class (Trapletti and Hornik, 2009), and the AUTO-ARIMA time-series analysis in the 'forecast package for R' we extrapolated the annual 1970–1995 fishing effort estimates backward to 1950 and forward to 2010 (Hyndman and Khandakar, 2008);
4. performing a Bray–Curtis cluster analysis of the annual total fish catch reported by country and taxon from 1950 to 2006, to highlight similarities in fish catch trends of fishing countries (Watson et al., 2004) and using the similarities to identify surrogates for those countries that did not provide fishing effort to the FAO online database (see Appendix D); and
5. searching the Web of Science (all available years) for information on the number of fishing days by various vessel/gear types, and using these estimates to convert the annual total kilowatt into kilowatt days (see Appendix E).

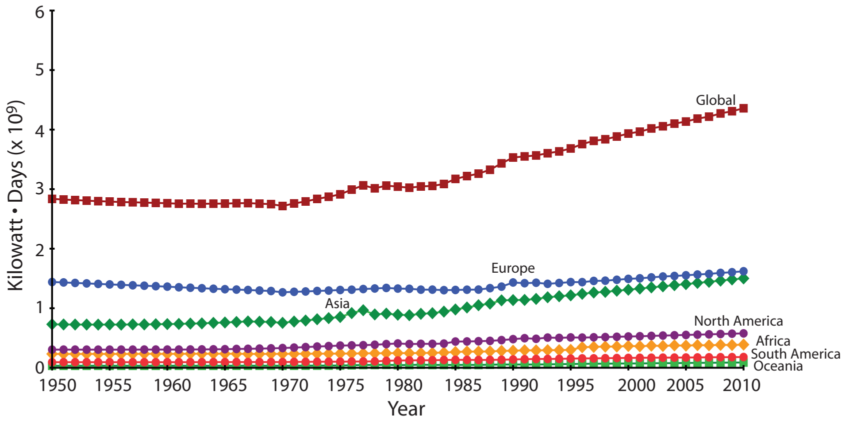

Fig. 1. Time-series of annual estimates of total fishing effort exerted by all countries globally, and by continent (1950–2010).

2.3. Data analysis and cross-validation

We analyzed the spatio-temporal trends in fishing effort by summing the data globally, by continent, country, GRT class, vessel/gear type. For visual and cross-validation purposes, we presented the mean estimates of total fishing effort by country and by decade, jointly with the time-series where appropriate. We cross-validated our results with the fishing effort estimates from literature reviews and with fishing effort estimates from EUROPA online data.

We provided a scoring system to evaluate the quality of our annual time-series data (1950–2010) for every fishing nation included in the analysis, as follows: (a) surrogates = 1; (b) copied forwards, backwards, or interpolation = 2; (c) forecast or backcast using AUTO-ARIMA = 3; and (d) raw data = 4 (see Appendix F). We also mapped the mean total fishing effort of fishing countries by decades, from 1950 to 2010, and the corresponding mean values of the data quality scores (see Appendix F).

3. Results and discussion

3.1. Global fishing effort

The estimated global total kilowatt days exerted by all fishing nations was nearly unchanged from 1950 to 1960. From 1961, there is an increasing trend in fishing effort (1.1% annual increase, calculated as percentage change among years), with the highest value (4.4 billion kilowatt days) – a 54% increase from 1950 to 2010 (Fig. 1).

Europe had the greatest fishing effort in 1950, but it then increased at only 0.2% per year to 1.6 billion kilowatt days by 2010 (Fig. 1). The fishing effort of Asia was second largest, increased at 1.2% annually, and was rapidly approaching that of Europe by 2010. North America showed a rate of increase of 1.1% annually, Africa of 0.9%, South America of 1.1%, while Oceania showed the least fishing effort (88 million kilowatt days by 2010), but with an average increase of 1.7% from 1950 to 2010.

Fishing vessels that FAO categorized as GRT class 5 (100–149.9 GRT) dominated global fishing (Fig. 2a). Globally, GRT class 5 vessels slightly decreased in total fishing effort from 1950 to 1970, but increased by 1.1% annually thereafter, yielding an estimated total of 2.7 billion kilowatt days by 2010. GRT class 5 vessels are predominantly from Europe, followed by Asia (Fig. 2b). Tonnage class 4 (50–99.9 GRT) fishing vessels showed 0.3% increase in total effort in 2010, and the highest value of 395 million kilowatt days by 2010. Tonnage class 3 fishing vessels (25–49.9 GRT) exerted the least effort. The total fishing effort of GRT 3 vessels increased by 0.5% annually from 1950 to 2010. Finally, the fishing effort exerted globally by GRT class 2 vessels increased by 1.4% annually, with an estimated peak value of 897 million kilowatt days by 2010 (Fig. 2a); these vessels are registered mostly in Asia (Fig. 2c).

The total global fishing effort exerted by trawlers (e.g., beam, otter, pair, or shrimp trawlers) decreased from 1950 to 1970 (Fig. 3a and b), but increased by 1% annually thereafter, reaching a peak value of 2.2 billion kilowatt days by 2010. Europe dominated the global fishing effort exerted by trawlers, followed by Asia (Fig. 3c). Vessels/gears that FAO categorized as 'Other Gear/Not Known' comprised the second largest fishing effort (Fig. 3a and b). Europe also dominated the global fishing effort exerted by vessels with unknown gears, followed by Asia (Fig. 3d). Longliners exerted the third largest fishing effort, with an average increase of 1% annually from 1950 to 2010, and a peak value of 232 million kilowatt days by 2010 (Fig. 3b). Vessels using hooks and lines showed the fourth largest fishing effort, with an average increase of 1.6% annually, and a peak value of 219 million kilowatt days in 2010 (Fig. 3b). Seiners deployed the fifth largest fishing effort, with an average increase of 0.4% annually from 1950 to 2010, and a peak value of 101 million kilowatt days by 2010 (Fig. 3b).

3.2. Fishing effort by countries within continents

Russia dominated the European fishing effort, followed by Spain, UK, and Portugal (Appendices G.1 and H). The total fishing effort of all the EU member countries was higher than the Russian fishing effort (Appendices G.1 and H). Japan initially dominated the Asian fishing effort, but this changed as China increased its effort from the late 1980s to the present (Appendices G.2 and H). Other Asian countries that exerted high fishing effort include South Korea, Taiwan, India, North Korea, Indonesia, Thailand, and Malaysia. USA and Canada dominated the North/Central American fishing effort (Appendices G.3 and H), and this was followed by Cuba, Panama, Mexico, and Guatemala.

South Africa initially dominated the African fishing effort, but Mozambique, Morocco, and Egypt showed rapid increases in fishing effort over time and became dominant in Africa (Appendices G.4 and H). The other countries that demonstrated high fishing effort include Namibia, Libya, Ghana, Equatorial Guinea, Mauritania, and Cameroon. South American fishing effort is increasingly dominated by Argentina, Brazil, and Venezuela (Appendices G.5 and H), followed by Chile, Ecuador, Peru, Colombia, and Uruguay (Appendix G.5 and H). Finally, New Zealand and Australia dominated the fishing effort in Oceania (Appendices G.6 and H).

3.3. Verifications, gaps, and implications

Our results demonstrated that the global fishing effort remained essentially unchanged from 1950 to 1970, but then increased there-

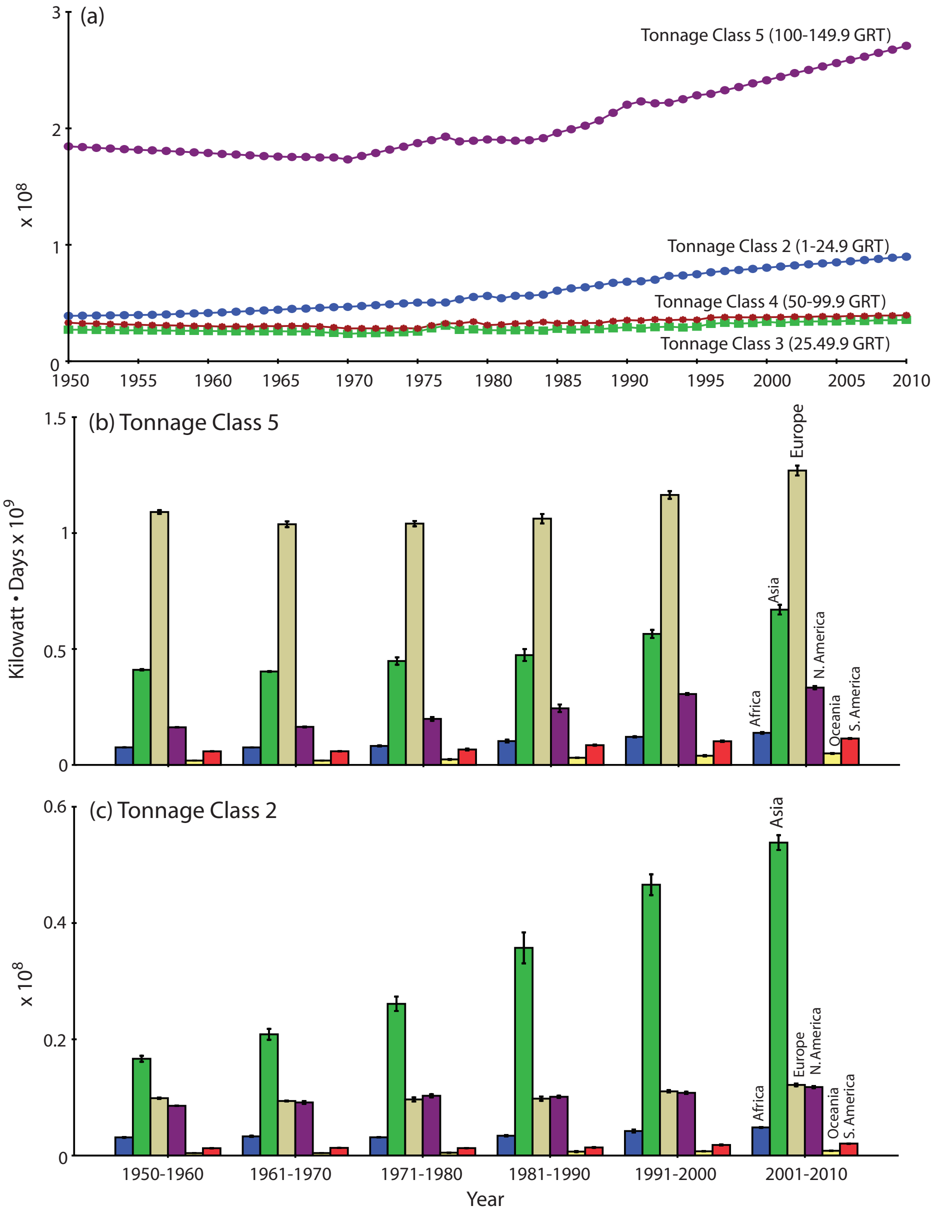

Fig. 2. Time-series of annual estimates of total fishing effort by gross registered tonnage class GRT (a). Also presented are the mean (SE) estimates per decade (1950–2010) by continent, for tonnage class 5 or 100–149.9 GRT (b), and tonnage class 2 or 1–24.9 GRT (c).

after, driven mainly by effort growth in Europe and Asia. Our findings agree with other global fishing effort analyses, although magnitudes sometimes differ. FAO (2009) also demonstrated the dominance of European fishing effort in terms of fishing vessels >100 tons, however, Asia had a greater number of vessels overall. Such differences illustrate the need for more comprehensive and accurate recording, archival, or, in cases where countries continue to fail to contribute to the FAO database, or similarly fail to make their fishing effort data accessible, the need for data reconstruction (Zeller et al., 2005).

The lower effort for other continents, i.e., North/Central and South America, Africa and Oceania reflects both the smaller fleet sizes of these continents and was due, at least in part, to poorer reporting to the FAO fishing fleet database (see Appendix C.1 and C.2). The most obvious of these deficiencies is the lack of any data from Australia.

To verify the accuracy of our estimates of fishing effort based on FAO data, we searched the peer-reviewed literature. We found that our estimates of fishing effort for Europe were consistent with an independent estimate of European fishing effort – i.e., about 6–8 million kilowatts annually, between 1987 and 1997, or about 1.6 billion kilowatt days if fishing vessels fish on average 200 days per year (Villasante, 2010) – see Fig. 1. We were unable to verify the data of other continents due to lack of independent estimates.

We demonstrated, however, that where data are sufficient, such as for the EU countries, our statistical approach of calculating fishing effort and filling data gaps provided estimates similar to those based on complete data (Villasante, 2010). This suggests that even if countries fail to provide the effort of their fishing vessels, but provide good data on other vessel characteristics such as length or tonnage, it will be possible to estimate their fishing effort. Evidently, given the potential differences in fishing vessel designs and engine power across the globe, it is still better that countries provide the essential details of their fishing vessels and fishing tactics. It is also helpful that FAO is developing a more comprehensive fishing vessel registry. Moreover, scientists studying fishing effort may contribute to the greater understanding of global trends in fishing effort by reporting variables that are comparable to those that we

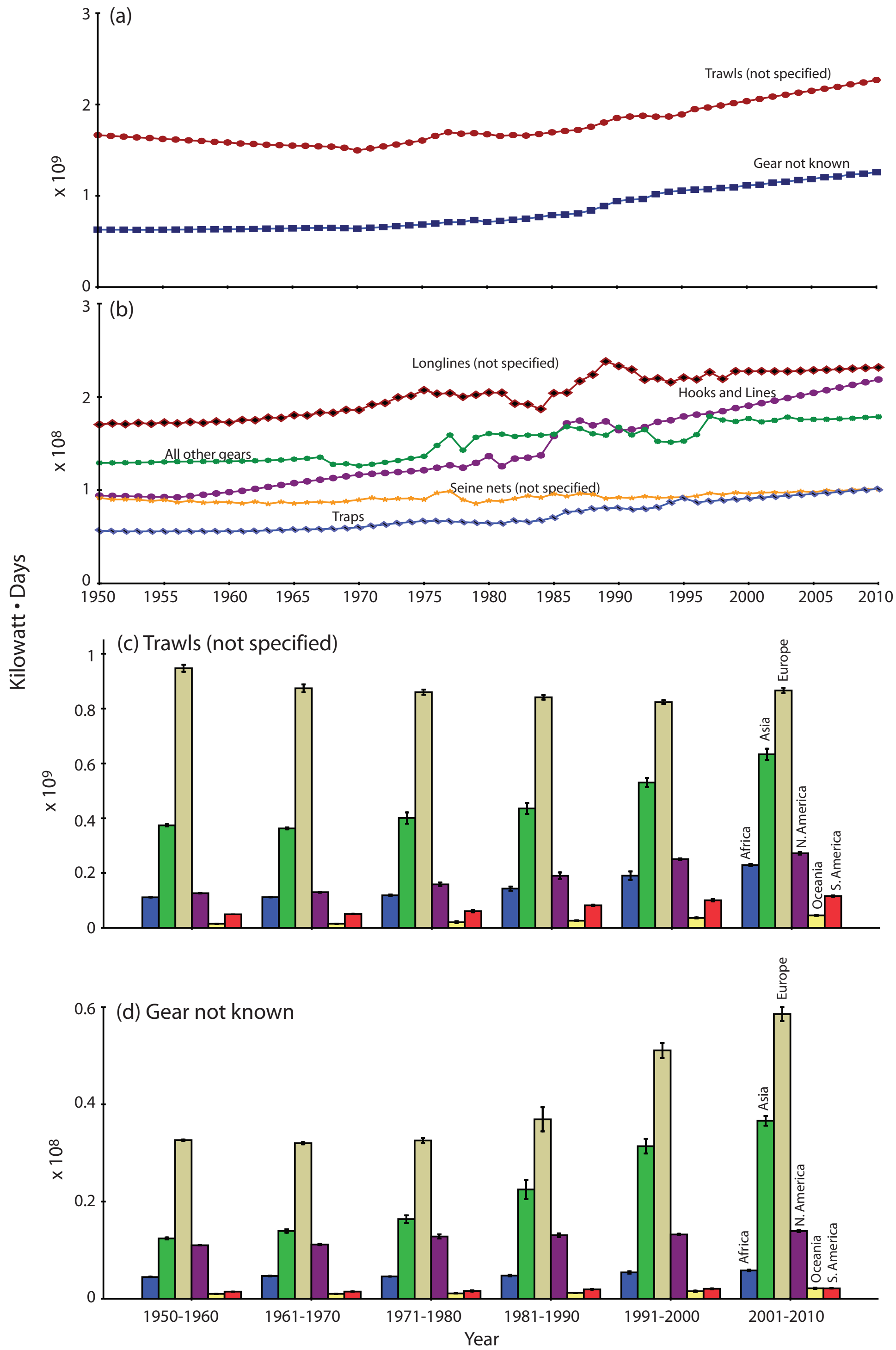

Fig. 3. Time-series of annual estimate of total fishing effort by vessel/gear type (a and b). Also presented are the mean (SE) estimates per decade (1950–2010) by continent, for "other trawls not specified" (c), and "gear not known" (d).

categorized in the introduction of this paper, and therefore would prove useful in cross-validations of various fishing effort studies.

Our analyses of the available global fishing effort data demonstrated several gaps and limitations, even after interpolation and extrapolation. Given these various limitations of existing global fishing effort data, we suspect that most of the published estimates of economic losses due to overcapacity and overfishing are underestimates, including that reported by the World Bank (2009). Notably, several fishing countries did not contribute any fishing effort data to the FAO (see Appendix C), without even considering the additional problems associated with illegal, unreported, and unregulated (IUU) fishing (FAO, 2008, 2009; World Bank, 2009).

Our results also support other studies (Srinivasan et al., 2010; World Bank, 2009) indicating that countries should re-evaluate their investment and subsidization policies, often articulated around further increases in fishing effort.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.fishres.2010.10.016.

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