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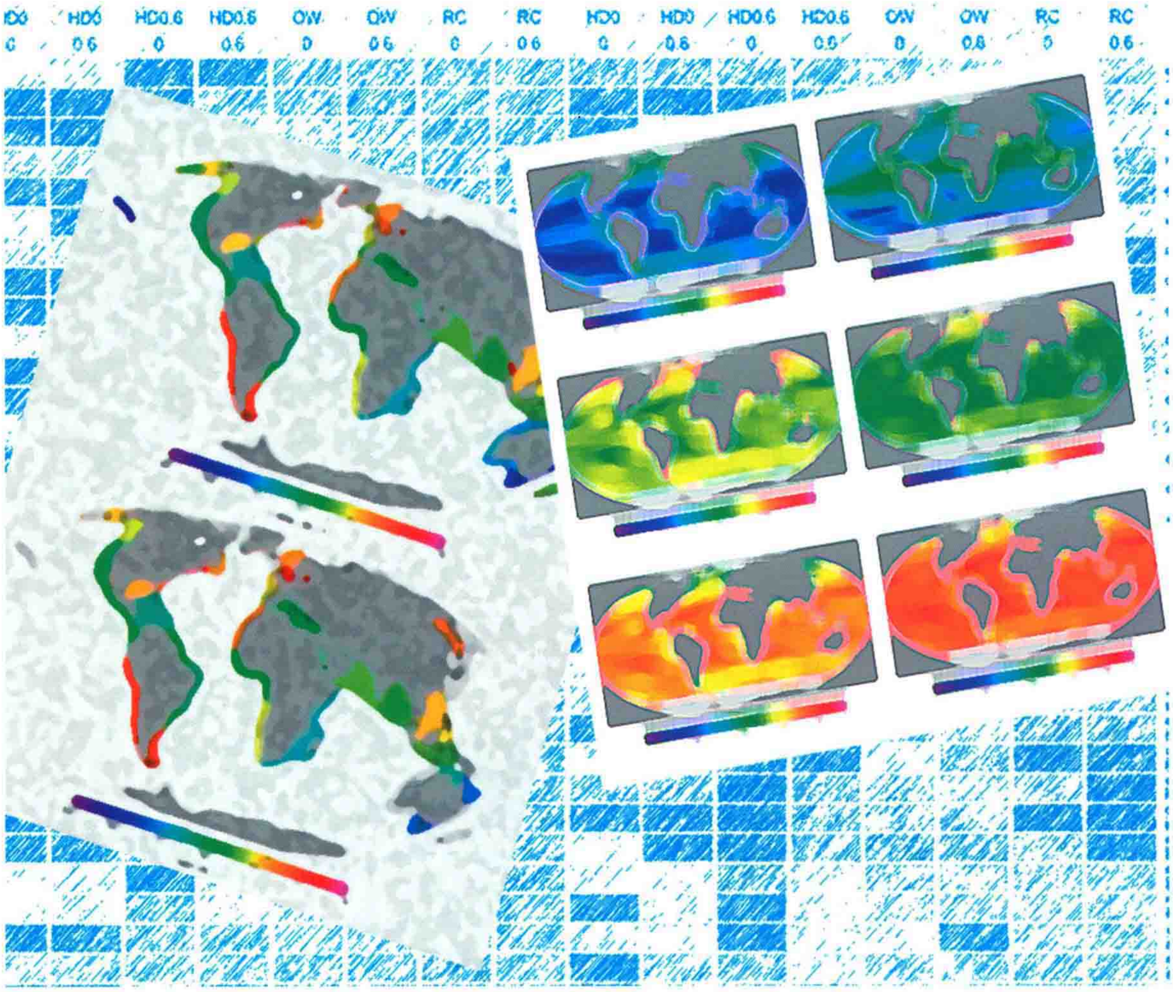

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DEVELOPING NEW APPROACHES TO GLOBAL STOCK STATUS ASSESSMENT AND FISHERY PRODUCTION POTENTIAL OF THE SEAS

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PREPARATION OF THIS DOCUMENT

FAO has been monitoring the state of the world's marine fish stocks since 1974, and it periodically produces the most authoritative report on the subject – *The State of World Fisheries and Aquaculture*. Information on the state of fishery sustainability is not only important for policy formulation, but also crucial to guide the fishing industry and its managers to develop effective harvest strategies. Moreover, sustainable fisheries require healthy ecosystems. To monitor ecosystem health, it is necessary to conduct ecosystem-level assessments that take into consideration both targeted and non-targeted species, interspecies interactions, and other factors that cannot be determined by looking at each stock in isolation. With these objectives, the Fisheries and Aquaculture Department of the FAO commissioned a study – Developing New Approaches to Global Stock Status Assessment and Fishery Production Potential of the Seas.

This circular presents the results of the study. It consists of two parts. Part 1 focuses on determining single-stock status and summarizes the results of simulation testing of four methods that can be applied to data-poor fisheries. Part 2 reports the results on the estimation of ecosystem-level production potentials based on satellite-based estimates of primary productivity.

Eighteen scientists around the world participated in this study: Andrew A. Rosenberg, Union of Concerned Scientists, United States of America; Michael J. Fogarty, Northeast Fisheries Science Center, National Marine Fisheries Services, National Oceanic and Atmospheric Administration, United States of America; Andrew B. Cooper, Simon Fraser University, Canada; Mark Dickey-Collas, International Council for the Exploration of the Sea, Denmark; Elizabeth A. Fulton, CSIRO, Australia; Nicolás L. Gutiérrez, Marine Stewardship Council, United Kingdom; Kimberly J.W. Hyde, National Marine Fisheries Services, National Oceanic and Atmospheric Administration, United States of America; Kristin M. Kleisner, Sea Around Us Project, University of British Columbia, Canada; Trond Kristiansen, Institute of Marine Research, Norway; Catherine Longo, National Center for Ecological Analysis and Synthesis, United States of America; Carolina V. Minte-Vera, Universidade Estadual de Maringá, Brazil, and Inter-American Tropical Tuna Commission, United States of America; Cóilín Minto, Galway-Mayo Institute of Technology, Ireland; Iago Mosqueira, European Commission Joint Research Centre, Institute for Protection and Security of the Citizen, Maritime Affairs Unit, Italy; Giacomo Chato Osio, European Commission Joint Research Centre, Institute for Protection and Security of the Citizen, Maritime Affairs Unit, Italy; Daniel Ovando, Sustainable Fisheries Group, University of California, Santa Barbara, United States of America; Elizabeth R. Selig, Betty and Gordon Moore Center for Science and Oceans, Conservation International, United States of America; James T. Thorson, Fisheries Resource and Monitoring Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, United States of America; Yimin Ye, Food and Agriculture Organization of the United Nations, Italy.

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ABSTRACT

Stock status is a key parameter for evaluating the sustainability of fishery resources and developing corresponding management plans. However, the majority of stocks are not assessed, often as a result of insufficient data and a lack of resources needed to execute formal stock assessments. The working group involved in this publication focused on two approaches to estimating fisheries status: one based on single-stock status, and the other based on ecosystem production.

For the single-stock status work, a fully factorial simulation testing framework was developed to assess four potential data-limited models. The results suggest that Catch-MSY, a catch-based method, was the best performer, although the different models performed similarly in many cases. Catch-MSY was more effective in estimating status over short time scales and could be particularly applicable for use in developing countries where data time series are often shorter. Harvest dynamics was the most important explanatory variable in determining performance, which emphasizes the importance of having accurate information on fishing effort and total removals.

For the ecosystem-level production analysis, the working group used satellite-based estimates of primary productivity by size classes and a more complete food web, which included more complete microbial pathways than earlier approaches. The working group also assembled estimates of ecological transfer efficiencies from a large number of energy flow network models to characterize uncertainty. The first-order estimates of fishery production potential indicated a potential yield of up to 180 million tonnes of fish, which could vary depending on the capacity to sustainably diversify the suite of species that are currently exploited. Planktivorous species provide the largest scope for growth. However, consideration of factors such as the ecological impact on other food web components, profitability of harvest operations, and marketability for these species must first be resolved. The realized production potential for planktivores may be much lower than their potential levels depending on the outcome of these considerations. The working group estimated that up to 50 million tonnes of benthic production could be potentially harvested, although this estimate is subject to similar constraints as those for planktivores. The greatest scope for growth in the benthic component may be found in the mariculture sector, subject to suitable environmental safeguards.

Ecosystem exploitation rates should not exceed 20–25 percent of available production, considering basic energetic constraints in marine ecosystems. Current harvest levels for benthivorous and piscivorous species (principally fish) exceeded these levels in higher-latitude ecosystems (subarctic-boreal and temperate) and were near or slightly below them in lower latitudes and upwelling systems. The estimates of the ratio of current catches to available production for planktivorous species are substantially lower, reflecting the production potential of currently underutilized species. However, targeted harvesting of selected planktivorous species does lead to relatively high exploitation rates for some species. Together, these results provide globally applicable methods for estimating fish stock status and fishery production potential.

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ABBREVIATIONS AND ACRONYMS

APE	absolute proportional error
AR	autoregression
BMSY	biomass at maximum sustainable yield
CMSY	catch-MSY
COM	catch only model
COM-SIR	catch only model – sampling importance resampling
DB-SRA	depletion-based stock reduction analysis
DCAC	depletion-corrected average catch
EwE	Ecopath with Ecosim
HD	harvest dynamics
ICES	International Council for the Exploration of the Sea
ID	initial depletion
LH	life history
LME	large marine ecosystem
MAPE	mean absolute proportional error
MPE	mean proportional error
mPRM	modified panel regression model
MSD	maximum single density
MSY	maximum sustainable yield
MTL	mean trophic level
NES LME	Northeast US Continental Shelf LME
OW	one-way trip (a type of harvest dynamic)
PE	proportional error
PPR	primary production required
PRM	panel regression model
RC	roller coaster (a type of harvest dynamic)
SIR	sampling importance resampling
SSCOM	state–space catch only model
TL	trophic level
TS	time series length
VGPM	Vertically Generalized Productivity Model

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OVERALL INTRODUCTION

Wild-capture fisheries provide a critical source of nutritional and economic benefits to people worldwide. In 2010, fisheries generated livelihoods and income for almost 38.5 million people (FAO, 2012) and currently fish provide approximately 3 billion people with almost 20 percent of their intake of animal protein. In the last half century, marine fisheries have been rapidly expanding and developing (Swartz *et al.*, 2010). Fishing fleets have also been increasing, both in number and extent, since the 1970s (Anticamara *et al.*, 2011; Watson *et al.*, 2013), although this growth has stabilized in the last decade (FAO, 2010). Concurrently, total landings increased from 16.8 million tonnes in 1950 to a peak of 86.4 million tonnes in 1996, but subsequently declined to 77.4 million tonnes in 2010 (FAO, 2012). With coastal populations projected to grow by 35 percent in the next 20 years, the demand for fisheries resources is likely to continue to increase.[1] The combined intensification in both pressures on and demand for fisheries resources necessitates a broad understanding of the state of global fisheries to support policy formulation and the development of effective marine management.

In spite of their importance, it remains a major challenge to determine the status and potential production of wild-capture fish stocks. Managers and policy-makers need information on individual fish stocks to evaluate their status so that effective management strategies can be developed. At the same time, it is also necessary to undertake ecosystem-scale assessments that account for the interactions between stocks, the impact of fishing on non-target fish, and other factors that cannot be determined by looking at each stock in isolation.

Costello *et al.* (2012) estimated that more than 80 percent of the global catch comes from stocks that have not been formally assessed. Formal stock assessments require substantial data and resources to complete. Therefore, data-limited approaches are needed to assess the status of global fish stocks and to develop benchmarks for the fishery production potential of the oceans. The working group addressed these challenges using two approaches to estimate fisheries status: one based on single-stock status, and the other based on ecosystem production. The single-species work stream focused on evaluating the operational performance of different methods for estimating stock status within a simulation framework to evaluate their performance robustly. This simulation framework can also be used to examine the performance of other data-limited and data-rich approaches. The ecosystem production work stream was tasked with developing estimates of fishery production for each large marine ecosystem (LME) and FAO statistical area based on overall primary production in each area. This information allows for the extracted production to be compared with the estimated total production in an LME or FAO area, which is useful for developing food security policies, for effective marine stewardship, and for understanding the potential gains in fishery production from enhanced ocean management. Results from both work streams can be used to compare current exploitation rates with estimated fishery production potential.

There is always a trade-off between risk and exploitation, and this study provides a suite of methods for evaluating fish stocks at greatest risk so that they can be prioritized for management and increased data collection. Estimating stock status and identifying regions that may be at risk for overexploitation are key components of moving towards ensuring sustainable exploitation. The work described in this report is an important step in investigating the performance of methods that can be used to estimate stock status. The results are not intended to provide direct advice to motivate management measures on specific fisheries, but to give an indication of the health of fish stocks and their production potential.

The approaches from the two work streams provide a more quantitative and consistent basis for evaluating global fish stock status than has previously been available. These estimates are vital for efforts to assess the health of marine ecosystems globally under data-limited situations.

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[1] www.earth.columbia.edu/news/2006/story07-11-06.php

PART 1

DETERMINING SINGLE-STOCK STATUS

1. INTRODUCTION

Managers and policy-makers need information on the status of individual fish stocks in order to manage marine fisheries resources sustainably, implement rebuilding plans for overfished species and increase production where possible. Formal stock assessments, often considered to be the gold standard in fisheries science, are available for a relatively small proportion of global stocks. Assessed stocks account for about 16 percent of harvested fish taxa (Ricard *et al.*, 2012), although the proportion of stocks assessed is likely to be lower for developing countries (Mora *et al.*, 2009). These assessments use all available data (e.g. catches, size and age distributions, surveys and tagging information) to quantify the rate of exploitation (F) in relation to that which is considered sustainable (F_{MSY}) and the relationship between historical and current stock biomass and the biomass that can produce maximum sustainable yield (MSY) (Branch *et al.*, 2011). This biomass ratio is commonly referred to as B/B_{MSY}.

In order to assess the status of fish stocks at the global level, FAO uses a combination of quantitative (formal) and qualitative stock assessments, using available information such as catch, abundance indices, spawning potential and age and size composition (FAO, 2012). In some cases, numerous types of data of varying quality are used for these assessments, but sometimes the only information that may be available is catch data (Branch *et al.*, 2011). These FAO assessments, which have been applied to 445 fish stocks since 1974, revealed that 30 percent of marine capture fisheries were overexploited and 57 percent of stocks were fully exploited in 2009 (FAO, 2012). Other research has estimated that 63 percent of assessed stocks require rebuilding to B_{MSY}; therefore, greater efforts are needed to improve the health of fisheries (Worm *et al.*, 2009). In general, these global assessments provide an important overall picture of the health of fish stocks, but they are based only on a limited number of stocks. In some cases, these assessments do not provide target or limit reference points that can be used for management. However, both the formal assessment methods and the FAO assessments still omit many small stocks, many of which are vital for food security, especially in developing countries and small island nations.

The majority of commercially exploited species have never been assessed and no reference points have been established for them. Most methods for calculating stock status in data-limited fisheries rely solely on catch data. There has been considerable controversy over the use of catch data to estimate stock status for unassessed fisheries (Branch *et al.*, 2011; Pauly, Hilborn and Branch, 2013). Nonetheless, some studies show that small, unassessed stocks may be in poorer condition than suggested by global estimates of fisheries status, based largely on assessed stocks (Costello *et al.*, 2012; Froese *et al.*, 2012). Although formal stock assessments remain the standard for determining stock status and exploitation rates that can be used to inform management action, they will continue to be unfeasible for many of the world's fisheries because of the data and technical capacity required.

Determining stock status typically requires time-series information on historical removals (e.g. catch and discards), information on trends in abundance (e.g. catch per unit effort) and assumptions about the underlying processes that regulate or affect fish stocks (e.g. a production function such as a Schaefer production model, recruitment and/or assumptions about the economic drivers of fisheries). Only landings data exist for many data-limited stocks, which require additional assumptions, information and methods in order to estimate stock status.

There are both mechanistic and non-mechanistic methods that use only catch data to obtain a picture of stock status. Non-mechanistic approaches to assessing stock status include stock status plots, which use catch time series to assign development stages to individual stocks based on catch levels in relation to the maximum or peak catch of the time series (e.g. Froese and Kesner-Reyes, 2002; Pauly, 2007; Kleisner *et al.*, 2013). However, these methods have been criticized for their lack of mechanistic underpinnings (Branch *et al.*, 2011). In the United States of America, Congress tasked the National Marine Fisheries Service with the setting of annual catch limits and accountability measures for each managed fishery by fishing year 2010 for all stocks experiencing overfishing and by fishing year 2011 for all other stocks in the fishery (Berkson *et al.*, 2011). This mandate affected both data-rich stocks for which traditional stock assessments could be conducted as well as data-limited stocks.