Suggested Title: Assessing the knowledge-base for commercially exploited marine fisheries with a new database of global stock assessments

Alternative Title 1: A new database of global stock assessments for exploited marine fisheries

Alternative Title 2: Assessing the geographic and taxonomic coverage of marine fisheries using a new database of global stock assessments

Suggested Running Title: A database of global stock assessments

Daniel Ricard * Cóilín Minto* Olaf Jensen †
Julia Baum‡

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*Dalhousie University, corresponding author
†University of Washington
‡NCEAS

Abstract

Data used to assess the status of individual fish stocks varies from very little information on many of the world's artisanal fisheries, to commercial landings at various levels of geographic and taxonomic aggregation, research surveys, and sophisticated population dynamics models that integrate many sources of information. Previous evaluations of the state of global fisheries have used catch or landings data, which may be poor proxies for fish stock abundances. A global compilation of stock assessment data in the mid-1990s enabled substantial syntheses of stock status; however the focus of this database was on stock-recruitment relationships and it is now 15 years out of date. To facilitate contemporary syntheses, we have assembled a comprehensive database of the most intensively studied commercially exploited marine fish stocks. The database includes time series of: total biomass, spawner biomass, recruits, fishing mortality, and catch; reference points; and ancillary information on the life history, management, and assessment methods for each stock. Here, we present the first overview of the structure and content of the database. We further evaluate the knowledge-base for assessed marine fishes. Globally, publicly available stock assessments were found for XX stocks (XX species of fishes representing XX families and XX species of invertebrates representing XX families), from XX countries included in XX management institutions. Assessments are available for only XX percent of global marine fisheries catches by weight and XX percent by value. There is substantial spatial variation in availability of assessed stocks, with XX percent coming from north temperate regions (North Atlantic, North Pacific). Geographic differences in assessment methods show that Statistical Catch at Age (SCA) models are widely used by the west coast of the U.S. (XX percent of assessments), regional fishery management organizations in the Pacific (XX percent of assessments), and New Zealand (XX percent of assessments); the east coast of the U.S. is transitioning from Virtual Population Analysis (VPA) to SCA (XX percent of assessments conducted since 2000 have used SCA); while VPA is still the dominant assessment technique in western Europe (XX percent of assessments).

Keywords: Marine fisheries, stock assessment, relational database.

1 Introduction

Marine wild capture fisheries provide more than 80 million tons of fisheries products (both food and industrial) per year and employ 43.5 million people (wild capture and aquaculture, FAO (2009)). At the same time, fishing has been recognized as one of the most widespread human impacts in the world's oceans (Halpern *et al.*, 2008), and the UN Food and Agriculture Organization estimates that two-thirds of fish stocks are fully exploited or overexploited (FAO, 2009). While many fisheries have reduced exploitation rates to levels that should promote recovery (Worm *et al.*, 2009), overfishing continues to be a serious global problem. Fishery managers are asked to address multiple competing objectives including maximizing yields, ensuring profitability, reducing bycatch, and minimizing the risk of overfishing. Given the enormous social and economic costs (Rice *et al.*, 2003) and ecosystems consequences (Frank *et al.*, 2005; Myers *et al.*, 2007) of collapsed fisheries, it is imperative that we are able to quickly learn the lessons of successful and failed fisheries from around the world.

Effective management of exploited fish populations generally requires an understanding of where the current population size and harvest rate lie in relation to the population size and harvest rate which maximize fishery benefits or limit the risk of overfishing. This process of quantitative determination of stock status and estimation of reference points is called stock assessment. Some fisheries in developing countries have apparently provided sustainable yields for long periods of time without formal stock assessment (e.g., many community-managed fisheries in Oceania, Johannes (2002)). This has been achieved by limiting harvest rates, often through gear restrictions or seasonal or area closures. In modern industrialized fisheries where fishing capacity exceeds the productivity of fished stocks, however, stock assessment is an integral component of responsible management (Hilborn and Walters, 1992).

Even in developed countries, however, not all stocks are assessed. For example, in 2007, of the 528 fish and invertebrate stocks recognized by the National Marine Fisheries Service (NMFS), only 179 or slightly over one third were fully assessed (National Marine Fisheries Service, 2008). An assessment by the European Environment Agency (EEA) in 2006 indicated that the percentage of commercial landings obtained from assessed stocks ranged between 66-97 percent in northern European waters and 30-77 percent in the Mediterranean (European Environment Agency, 2009). The New Zealand Ministry of Fisheries reports the status of 117 stocks or sub-stocks out of a total of 628 stocks managed under New Zealand's Quota Management System (New Zealand Ministry of Fisheries, 2009). In Australia, 98 federally managed stocks have been assessed (Wilson *et al.*, 2009) out of an unknown total. The extent to which stocks are assessed elsewhere in the world is currently unknown.

The global database of fishery landings compiled by Food and Agricultural Organization of the United Nations (FAO, 2009) and synthesized by the Sea Around Us project (Watson *et al.*, 2004) has proven to be a valuable resource for understanding fishery status; however, catch data alone can be misleading when used as a proxy for stock size. Many papers have used these catch databases to examine changes in fishery status (Worm *et al.*, 2006), including changes in trophic level (Pauly *et al.*, 1998; Essington *et al.*, 2006; Newton *et al.*, 2007). Most of these analyses rely (either explicitly or implicitly) on the assumption that catch or landings is a reliable index of stock size. Critics have pointed out that catch can change for a number of reasons unrelated to stock size, including changes in targeting, fishing restrictions, or market preferences (de Mutsert *et al.*, 2008; Murawski *et al.*, 2007; Hilborn, 2007). Even when catch is standardized by the amount of fishing effort (catch-per-unit-of-effort, CPUE), it can be an unreliable index of relative abundance (Hutchings and Myers, 1994; Harley *et al.*, 2001; Walters, 2003; Polacheck, 2006). Stock assessments consider time series of catch along with other sources of information such as: natural mortality rates, changes in size or age composition, stock-recruitment relationships, and CPUE of different sectors or of fishery-independent surveys. Because they integrate across multiple sources of information, stock assessment models are thought to provide a more accurate picture of changes in abundance than catch data alone (Sibert *et al.*, 2006). Yet, without a current and comprehensive database of stock assessments, scientists wishing to conduct comparative analyses of marine fish population dynamics and fishery status have little choice but to use problematic catch data.

The first global database of stock assessment information, the Myers Stock Recruitment Database, was developed by Ransom Myers and colleagues in the mid-1990s (Myers *et al.*, 1995b). While the database was primarily known for its time series of stock and recruitment, it did contain time series of fishing mortality rates for many stocks but biological reference points were largely absent. The original release version of the Myers database (Myers *et al.*, 1995b) contained approximately 700 assessments, including spawning stock size and recruitment time series for 274 stocks representing 92 species as well as time series of fishing mortality rates for 144 stocks (DOUBLE-CHECK NUMBERS IN REPORT + WEBSITE). It was used to: 1) decisively answer the question of whether recruitment shows any relationship to spawning stock size (Myers and Barrowman, 1996), 2) investigate potential depensation in stock-recruitment relationships (Myers *et al.*, 1995a; Liermann and Hilborn, 1997), 3) investigate density-dependent juvenile mortality (Myers, 2001; Minto *et al.*, 2008), and 4) develop informative Bayesian priors on steepness (Myers *et al.*, 1999, 2002; Dorn, 2002) , amongst others. The Myers database has also been used for several studies of collapse and recovery of exploited fish populations (Hutchings, 2000, 2001; Hilborn, 1997). (add NEWEST PAPERS USING ORIGINAL DB) (Garvey *et al.*, 2009)

Although the original Myers database (Myers *et al.*, 1995b) has proven to be a valuable resource, it is now fully 15 years out of date. This means that for many of the stocks in the original database there are potentially 15 more data point entries. For depleted stocks, these additional 15 years include observations at low stock size which are critical for defining the slope of the SRR near the origin and evaluating evidence for depensation. In addition, there have been numerous improvements in stock assessment methodologies (including important advances in statistical catch-at-age or catch-at-length models) and assessments have been conducted for the first time for many species.

Previous meta-analyses of fishery status have been hampered by the lack of a global assessment database containing biological reference points (BRPs, e.g., the biomass and fishing mortality rate that produce maximum sustainable yield, BMSY and FMSY). Knowledge of BRPs is important if stocks are to be managed for high yields that can be sustained over time (Mace, 1994). Without information on reference points, previous analyses of stock assessments or catch data have been forced to use arbitrary thresholds to define fishery status, such as the greatest 15 year decline (Hutchings and Reynolds, 2004) or 10 percent of maximum catch (Worm *et al.*, 2006). Ad hoc reference points based on some fraction of the maximum of a time series also have undesirable statistical properties and can result in false collapses when applied to inherently variable time series of catch or abundance (Wilberg and Miller, 2007; Branch, 2008). Complicating comparisons of fishery status is the fact that different BRPs are used in different parts of the world and even the same BRP can be used in a different manner, for example, as a target or a limit.

Here we present a new global database of stock assessments for commercially exploited marine fish populations. The database is an update and extension of that developed by Ransom Myers, and is named the RAM Legacy database in honor of his pioneering contribution. This effort is the first global stock assessment database to:

1. Use a formal relational database structure;
2. Use source control so that previous release versions are maintained;
3. Include metadata related to the geographic location of the stock, the type of assessment model used, and the original source document for the assessment data;
4. Include biological reference points and stock-specific life history information.

We use the database to assess the knowledge-base for management of marine fish populations and address the following questions:

1. What fraction of world wild-capture fishery landings come from assessed stocks and how does this proportion vary by region?
2. What are the taxonomic and geographic biases, if any, in assessed stocks?
3. What is the temporal coverage of stock assessments, i.e. how far back do stock assessments look when reconstructing trends in abundance?
4. Which stock assessment approaches are used and how does this vary by region?
5. What biological reference points are reported in assessments and how does this vary by region?
6. How accessible is stock assessment information in different regions?

2 Methods - was "The RAM Legacy database: structure, scope, and method of development"

Publicly available stock assessments from XX fisheries agencies were collated by recorders who then transferred the available information to a spreadsheet template for inclusion in the relational database management system.

2.1 Database structure and design

The database follows a relational model and is implemented in the Open Source PostgreSQL relational database management system (PostgreSQL Global Development Group, 2009). The database design houses tables for: assessment metadata, timeseries values, timeseries units, biometrics (catch-all term for point estimates), biometric values, spatial information, management body, and taxonomy. An entity relationship diagram detailing the data structure is presented in the Supporting Information.

2.2 Data sources and entry

Stock assessment reports were the primary data source, and were obtained either from the online site of the relevant management agency or directly from stock assessment scientists. Given the range of assessment types, people and agencies involved, it was necessary to design a flexible data entry protocol that captures all pertinent information.

Data were entered, by an assessment recorder (preferably an assessment author), into a spreadsheet template file, which has three worksheets: (1) meta, (2) biometrics, (3) timeseries. The template was flexible in that stock-specific information could be added depending on the scope of the information contained within the assessment. The 'meta' worksheet contained information about the stock (e.g. taxonomic information), the recorder entering the data, and references for the stock assessment document. The 'biometrics' worksheet was where point estimates (not time series) were entered. This included life history information, biological reference points, as well as details about the time series data such as the age and sex of spawners, the ages used to compute the fishing mortality etc. The 'timeseries' worksheet contained the entered time series data for the stock. The main variables entered

were: year, SSB (spawner stock biomass), R (recruits), F (fishing mortality), and TB (total biomass). The units for each of these were also entered. Detailed descriptions of what to enter (i.e. abbreviations for the units etc.) are found at: http://www.marinebiodiversity.ca/RAMlegacy/srdb/updated-srdb/ram-ii-stock-recruit-database-srdb-instructions-for-contributing-data. The completed assessment spreadsheet and accompanying assessment document were then submitted online to:
http://www.marinebiodiversity.ca/RAMlegacy/ramlegacy-bug-reporting.

2.3 Data integrity and quality control flow

The goal of the database quality control was to help ensure that the data entered mirror those present in the assessment document. The process consisted of entering the submitted assessment spreadsheet into a development database from which an automatic summary document was generated (using Perl and LaTex). This document contained: summary details of the stock, a selection of biometrics and ratios for comparison (e.g. current biomass relative to the reference point), and time series plots of the biomass, recruitment, and exploitation trajectories. This "Quality Assurance/Quality Controlled (QA/QC)" document was then returned to the assessment recorder and subsequent correspondence was captured in a Plone bug tracking system so that an electronic trail was established. Once the assessment recorder checked the QA/QC document and, if necessary, amended the assessment spreadsheet, the final spreadsheet was entered into the operational database and a quality controlled flag is inserted to signify that the data have passed this check.

2.4 Data products from the database contents

To facilitate analyses, a variety of data products, typically time series with certain criteria (e.g. all SR pairs with ≥ 25 years of data), were constructed from the database contents. These products were assembled as database views using the Structured Query Language (SQL).

2.5 Database access

The database was designed to allow entry at multiple levels. Users familiar with Structured Query Language (SQL) can query the database directly from the analytical software of choice via the appropriate Open Database

Connectivity (ODBC) connection (examples in the Supporting Information). Database views assist this level of entry by formatting data to be returned in column format such as those typically held in spreadsheets. This entry approach minimizes the risk posed by the alternative static copy, whereby changes enter and are inherited in the process of dissemination (Barbrook *et al.*, 1998, for a literary example). Notwithstanding this risk, a static release version in spreadsheet format is to be made available with this article.

2.6 Links to related databases

To facilitate integration of the RAM Legacy database with other fish and fisheries-related databases, such as Fishbase (Froese and Pauly, 2009) and the Sea Around Us Project's (SAUP) global landings database (Watson *et al.*, 2004), each species present in the RAM Legacy database was assigned a matching FishBase species name and species code as well as the SAUP taxon code. Additonally, each stock was assigned to a primary, secondary, and tertiary Large Marine Ecosystem. These steps ensure that researchers using data from the database can easily find matching data from other data sources without unnecessary linking difficulties.

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