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

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Abstract

Data to assess the status of individual fish stocks varies widely, from very little information of any kind on many of the world's artisanal fisheries, to landings (at various levels of geographic and taxonomic aggregation), research surveys, and sophisticated population dynamics models that integrate many different sources of information. Previous evaluations of the state of global fisheries have been based on 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stock status; however the focus of this database was on stock-recruitment relationships and it is now nearly 15 years out of date. To facilitate synthesis, we have assembled a comprehensive database of the most intensively studied commercially exploited marine fish stocks, which includes time series data of spawner biomass, recruits, fishing mortality, and catch as well as fisheries reference points, and ancillary information about the life history, management, and assessment methods for each stock. Here, we present the first overview of this database. We describe the structure and contents of the database, and 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. Together, 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). There are also geographic differences in assessment methods. Statistical catch at age (SCA) models have become widely used on the west coast of the U.S. (XX percent of assessments), by regional fishery management organizations in the Pacific (XX percent of assessments), and in New Zealand (XX percentof assessments). Virtual population analysis (VPA) is still the dominant assessment technique in western Europe (XX percent of assessments). The east coast of the U.S. is transitioning from VPA to SCA (XX percent of assessments conducted since 2000 have used SCA).

Keywords: stock assessment

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 thought to be 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 extremely 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 700 time series, 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) and 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 nearly 15 years out of date. This means that for many of the stocks in the original database there are now potentially 15 more pairs of spawning stock size and recruitment estimates. 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. In addition, there have been numerous improvements in stock assessment methods (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 (Branch, 2008; Wilberg and Miller, 2007). 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.

In this paper, 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 a variety of fisheries agencies were collated and the documents containing the assessment results were gathered. The available information about the different stocks was then transfered to a spreadsheet template for inclusion in a 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 body 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 are 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 is flexible in that stock-specific information can be added depending on the scope of the information contained within the assessment. The 'meta' worksheet contains information about the stock (e.g. taxonomic information), the recorder entering the data, and references for the stock assessment document. The 'biometrics' worksheet is where point estimates (not time series) are entered. This includes 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 is where time series data for the stock from its assessment is entered. The main variables to be entered are: year, SSB (spawner stock biomass), R (recruits), F (fishing mortality), and TB (total biomass). The units for each of these are 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 are the submitted online (http://www.marinebiodiversity.ca/RAMlegacy/ramlegacy-bug-reporting).

2.3 Data integrity and quality control flow

One important aspect of the database is that it undergoes a quality control procedure. The goal is to help ensure that the data entered mirror those present in the assessment document. The process consists of entering the submitted assessment spreadsheet into a development database from which an automatic summary document is generated (using Perl and LaTex). This document contains: 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 is then returned to the assessment recorder and subsequent correspondence is captured in a Plone bug tracking system so that an electronic trail is established. Once the assessment recorder has checked the QA/QC document and, if necessary, amended the assessment spreadsheet, the final spreadsheet gets 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 are constructed from the database contents. These products are assembled as database views using the Structured Query Language (SQL).

2.5 Database access

The database is 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). 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 hassle.

3 Results

Available data (note coverage and biases in this section) In total, recent stock assessments for XX (?) marine fish and XX invertebrate populations are included in the RAM Legacy database (Version 1.0, 2010). These include all stocks assessed by federal agencies in the U.S. (National Marine Fisheries Service (NMFS), n=XX), Canada (Department of Fisheries and Oceans (DFO), n=XX), New Zealand (NIWA and ??, n=xx), by Regional Fisheries Management Organizations (RFMOs) in the Northwest Atlantic (Northwest Atlantic Fisheries Organization (NAF0), n=XX), Atlantic (International Commission for the Conservation of Atlantic Tunas (ICCAT), n=XX), ... In addition, a subset of stocks

-distinction in assessments: do they exist and we have just not entered them? or do they not exist?

num of marine fish populations for there are stock assessments:

-taxonomic coverage (family, species), trophic level (and/or pelagic, demersal.....), habitat, diversity, ... Assessed populations are from XX different species and XX families, thus comprising a small fraction of marine fish biodiversity. Figure B.2

-out of all diversity Compare taxonomically and geographically to world fisheries catches.... number of the top 10 (or top 100) fisheries for which there are stock assessments (number of these that are for marine fishes vs. marine invertebrates)

- examine geographic coverage, Geographically, Figure B.2

Commercial?: -those that are commercially valuable, or some incidentally caught species of conservation concern (e.g. sharks, ...?)

number per management unit, per country, per multinational -transparency of management: which countries are transparent, and which are not

number of years included in each assessment = how long do we know about? Figure B.2 -types of assessment methodology: what percent are VPA, age-stuctured, production models etc. and break down by country -which ones have reference points? -difference between the maximum and minimum of each stock (¿50 percent i.e. is this why they are assessed?; but how much would they vary just with natural variability?) -give overview of spatial, temporal coverage of Ram's data, and then compare to what we have....

4 Discussion

4.1 Using a Relational Database Management System

Housing assessments in a Relational Database Management System (RDBMS) allows mutliple users to concurrently access and extract subsets of persistent data in an efficient and reproducible manner. With the development of Application Processing Interfaces (APIs) that allow analytical softwares to directly communicate and extract data from the database, a common data environment is established, independent of ones choice of analytical software e.g. (SAS:SAS ACCESS, Matlab: Matlab/Database, R:RDBI/RODBC, Perl:DBI...). In all these applications the same SQL query will extract the same data. In contrast, manipulating flat text files or spreadsheets for importing into a specific analytical software runs the risk of losing data integrity and becomes impractical with large, non-rectangular, datasets. One potential downside of using an RDBMSs is that it requires researchers to learn Structured Query Language (SQL) to extract data. The basic SQL needed to extract data from the RAM Legacy Database can be quickly learned and will further assist the researcher in understanding the structure of the various data within assessments. Furthermore, RDBMSs form the server back-end to a great many applications of interest to ecologists, including web-clients and GIS softwares. Thus, learning SQL can assist the researcher in availing of and further developing the tools required to explore large and increasingly complex datasets.

4.2 Biases

4.2.1 Geographic bias

Global geographic biases in the amount of assessments entered per LME exist (Figure B.2). A large proportion of entered assessments come from North America, Europe, Australia, New Zealand and the High Seas. Few assessments are entered from regions such as Oceania, South America, Indian Ocean and the Western Pacific. The question of geographic bias relates to whether: 1) an assessment is conducted on a stock; 2) it is possible to access the assessment; and 3) the non-exhaustive collation we undertook may have overlooked the assessment . Whether an assessment is conducted for a given stock depends upon a multitude of factors, including the economic value of the stock and availability of fiscal resources to collect the data required for an assessment. How accessible assessments are for entry depends upon the transparency and access policies of the relevant management agencies, which varies geographically. Our incomplete search for assessments could also give rise to geographic biases, as concerted collation efforts have only been conducted in those assessment-rich regions of Figure B.2. It is hoped that readers of this article can assist in this regard.

4.2.2 Taxonomic bias

Taxonomic biases in those assessed from those caught include... Note that this analysis does not account for discarding or unreported catches (Pauly *et al.*, 2002; Pitcher *et al.*, 2002).

4.3 Caveats and limitations

Assessment outputs e.g. biomass timeseries, are estimates, not raw data. The uncertainty associated with these estimates should be carried forth in subsequent analyses. The RAM Legacy database structure allows for estimates of uncertainty (standard errors, 95% credible/confidence intervals), however these estimates are only occassionally provided because they aren't produced by the assessment model (e.g. non-bootstrapped VPA assessments) or the focus of the assessment document was on location (e.g. mean biomass), not the associated uncertainty. Note that this view is changing with the advent of MCMC aproaches to Bayesian inference for assessments, bootstrap methods, statistical catch-at-age models and a focus on uncertainty (Walters and Maguire, 1996). As with any analysis, clearer inference on the strength of a signal is available when all uncertainty in the data is carried forth. This represents a difficulty for large-scale analyses of fisheries data in that in an ideal world one would access the raw data per sub-unit (e.g. stock) and carry forth the uncertainty at all levels of the analysis. In the case of assessments, the raw data is typically catch-at-age matrices and potentially survey indices. To understand the fleet characteristics and survey stratification schema for each stock in a potentially global meta-analysis would be extremely time consuming and error-prone. So, the expert opinion of those researchers most familiar with the data, stock assessment authors, is used but without accompanying uncertainty estimates the strength of conclusions drawn may be weakened.

4.4 Continuity

It is anticipated that the RAM Legacy database will continue to grow with new and updated assessments, as they appear. The ultimate goal is to provide a data standard for researchers, particularly providers, to use data from multiple regions to assist in their own applied and fundamental research. The greatest assistance in realizing this goal would be the devlopment of a standard for assessment reporting. For example, ICES assessments have a very regular standard, including agreed-upon reference points and regular estimate reporting, developed by ..... This makes the process of data collation much more routine than unstandardized documents where the recorder trawls through a report for information. Certainly different stocks and regions require different formats but the basic output tables, consisting of total and spawning biomass, recruitment, catch/landings, estimated fishing mortality over vulnerable age groups and their associated uncertainties would streamline the process immensely. Better still, a process whereby the assessment spreadsheets are filled out at each assessment meeting would be the least error prone method. In return, the assessment scientists can access results for a global collection of assessments to further their own research initiatives in population assessment and management. Other products include management agency level reports containing summaries of all stocks within their remit. Future versions to the database will also include timelines of management actions per stock.

Availability of the database

Contributions or corrections to the existing database, as well as requests to use the database (subject to standard "Fair Use" policies), should be directed to the corresponding author.

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A Tables

B Figures

B.1 Figure legends

Figure 1. Global map of Large Marine Ecosystems (LMEs) showing the number of stock assessments present in the database for each LME.

Figure 2. Temporal coverage of (A) catch/landings, (B) spawning stock biomass and (C) recruitment. The temporal coverage for individual assessments is represented by thin alternating black and grey horizontal lines in the main panels. Thick horizontal lines at the base of each main panel represent the time periods which are present in 90% (black) and 50% (grey) of all series for that data type. Subfigure histograms contain the frequency of occurrence of the various timespans without reference to time period. Solid and long-dash vertical lines within the subfigures represent the median, 2.5% and 97.5% quantiles, respectively.

Figure 3. Taxonomic coverage of assessed marine species present in the Myers II database. The circle located near the middle of the circular dendrogram represents kingdom Animalia and each subsequent branching represents a different taxonomic group (Kingdom to Phylum to Class to Order to Family to Genus to Species). The width of each line is proportional to the square root of the number of assessments in the database. The outermost lines represent species and the number of lines is the number of assessments for each species. The names of multi-assessment species are not repeated on the outermost portion of the dendrogram but continue counter-clockwise from the first entry. Note that branch lengths are chosen for graphical purposes and do not convey phylogenetic distance.

B.2 Figures

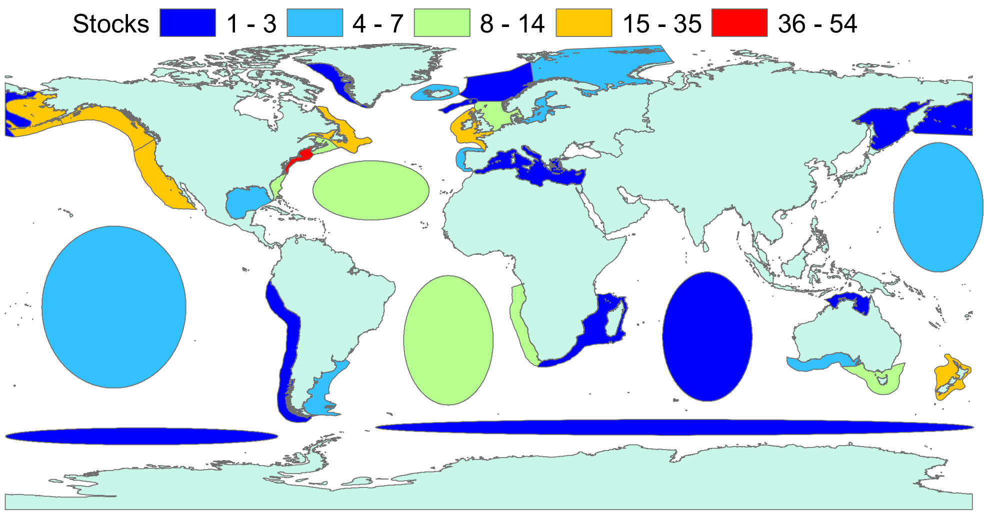

Figure 1:

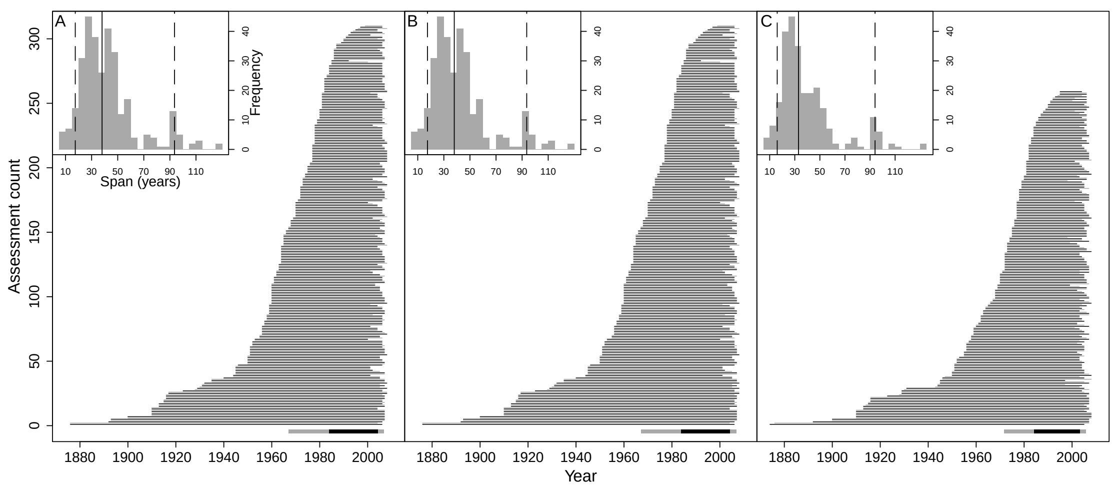

Figure 2:

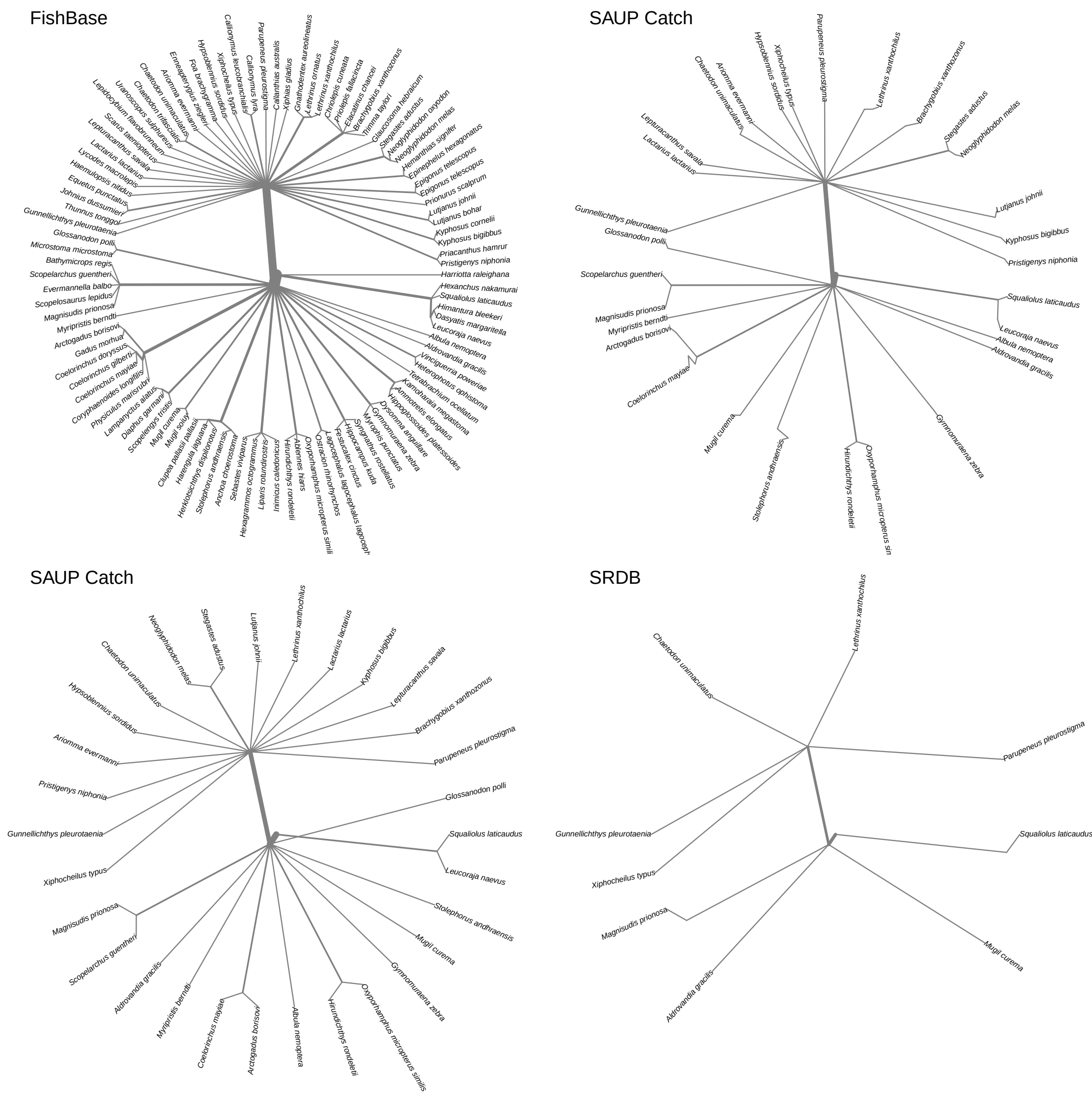
FishBase
SAUP Catch
SAUP Catch
SRDB
Lethrinus xanthochilus
Chaetodon unimaculatus
Parupeneus pleurostigma
Gunnellichthys pleurotaenia
Squaliolus laticaudus
Xiphocheilus typus
Magnisudis prionosa
Mugil curema
Aldrovandia gracilis

Figure 3:

C Supporting Information

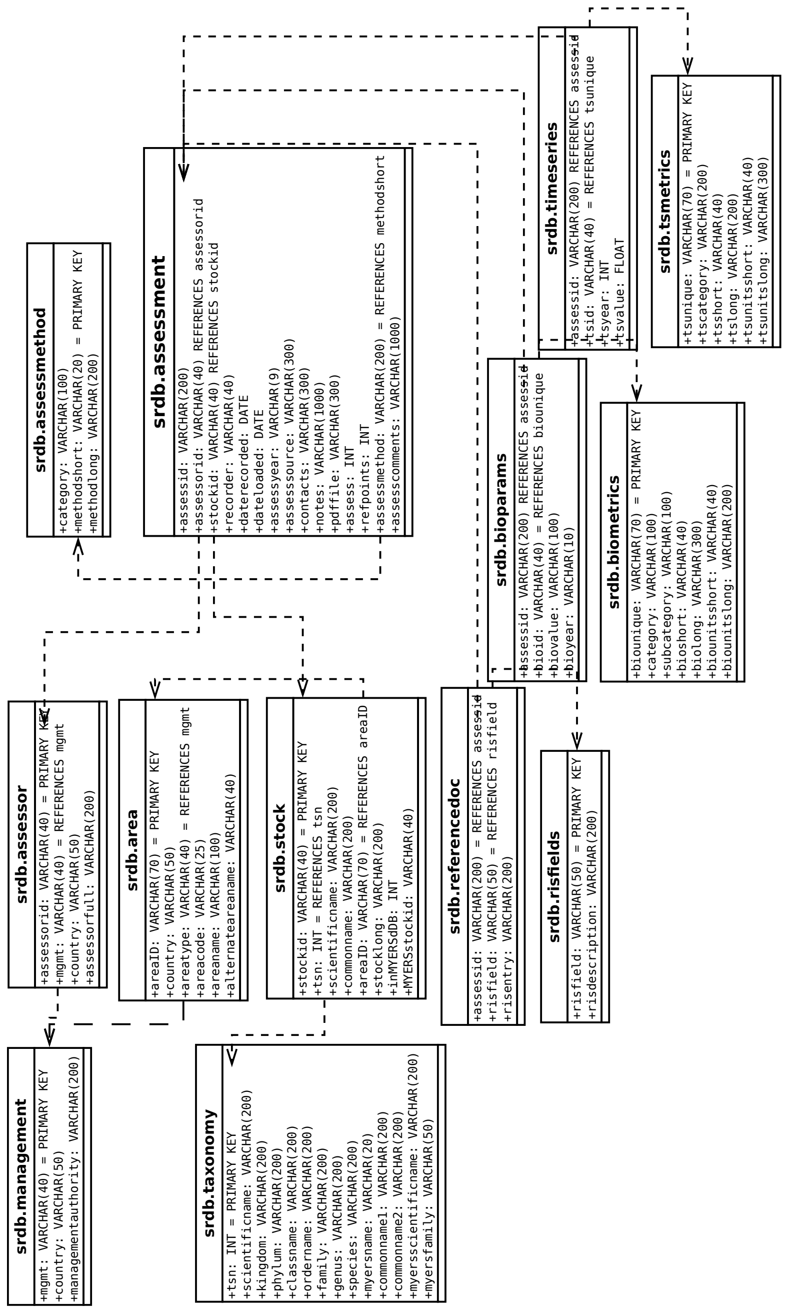

Figure 4: Entity relationship diagram of the RAM legacy database.