Assessing the knowledge-base for commercially exploited marine fishes and invertebrates with a new global database of stock assessments

Alternative Title 1: A new global stock assessment database for exploited marine species

Alternative Title 2: Understanding marine population dynamics using a new global database

Suggested Running Title: A new global stock assessment database

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

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[*]Department of Biology, Dalhousie University, Halifax, NS B3H 4J1, Canada
[†]Scripps Institution of Oceanography, UCSD, 9500 Gilman Drive, La Jolla, CA 92093-0202, USA
[‡]School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195-5020, USA

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of stock status; however the focus of this database was on stock-recruitment relationships and it is now 15 years out of date.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 324 stocks (288 species of fishes representing 45 families and 36 species of invertebrates representing 12 families), from 18 national and international 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, meta-analysis, population dynamics models, relational database, stock assessment, synthesis.

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 having one of the most widespread human impacts in the world's oceans (Halpern *et al.*, 2008), and the Food and Agricultural Organization of the United Nations (FAO) estimates that two-thirds of fish stocks globally are fully exploited or overexploited (FAO, 2009). While many fisheries have reduced exploitation rates to levels that should promote recovery, overfishing continues to be a serious global problem (Worm *et al.*, 2009). 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 from successful and failed fisheries from around the world.

Effective management of exploited fish populations generally requires an understanding of where the current size and harvest rate lie in relation to the size and 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, however, where fishing capacity exceeds the productivity of fished stocks 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 FAO (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; Costello *et al.*, 2008), 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, however, biological reference points were largely absent. The original release version of the Myers database (Myers *et al.*, 1995b) contained 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. 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; Garvey *et al.*, 2009), 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) . The Myers database has also been used for several studies of collapse and recovery of exploited fish populations (Hutchings, 2000, 2001; Hilborn, 1997)..

Although the original Myers database (Myers *et al.*, 1995b) has proven to be a valuable resource, it is now 15 years out of date. For stocks that were depleted in 1995, these additional 15 years include valuable observations at low stock size or of a recovering population, both of which are critical for estimating population dynamics parameters such as the behaviour of the stock-recruitment relationship near the origin. 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 total/spawning biomass and fishing mortality rate that produce Maximum Sustainable

Yield (MSY), B_{MSY} and F_{MSY}). 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 non-biological 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 software to organise release versions;
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 have used 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 is the temporal coverage of stock assessments, i.e. how far back do stock assessments look when reconstructing trends in abundance?
3. What are the taxonomic and geographic biases, if any, in assessed stocks?
4. Which stock assessment approaches and biological reference points are used and how does this vary by region?

Methods

The RAM Legacy database

The RAM Legacy database is a global relational database designed and developed to store data from all current and accessible population dynamics model-based fisheries stock assessments for marine fish and invertebrate populations. Time series of spawning stock biomass (SSB), total biomass (TB), recruits (R), total catch (TC) or landings (TL), and fishing mortality (F) from individual stock assessments form the core of the database. Apart from catch/landings, these time series are not raw data, but rather the output of population dynamics models; depending on the type of assessment model not all of these time series were available for every stock. The database also contains details about the time series data, including the age and sex of spawners, age of recruits, and the ages used to compute the fishing mortality, as well as BRPs and some life history information (e.g. growth parameters, age and length at 50% maturity, natural mortality). Metadata for each stock assessment consists of taxonomic information about the species (retrieved from the Integrated Taxonomic Information System (ITIS) (http://www.itis.gov)), the geographic location of the stock (primary, and in some cases, secondary and tertiary Large Marine Ecosystem, LME), the management body that conducted the assessment, the assessment methodology, the reference for the stock assessment document, the name of the recorder entering the assessment data, and the date the assessment was entered. Many assessments, particularly those for invertebrates, were based only on CPUE time series rather than population dynamics models. While we included these in the database, the analyses presented here focus on stocks assessed by proper assessments.

We employed a variety of search methods in an attempt to obtain all recent fisheries stock assessments. Publically available stock assessment reports available from the internet were the primary data source. These reports were obtained either from the website of the relevant management agency or directly from stock assessment scientists. Assessments also were obtained from the primary literature and through personal contacts at fisheries management agencies. Significant contributions also were made by the other members of the National Center for Ecological Analysis and Synthesis (NCEAS) working group "Finding common ground in marine conservation and management". Relevant assessment data were first transferred into a standardized spreadsheet template by a number of recorders, including ourselves, assessment authors, our NCEAS collaborators, and associated graduate students and postdoctoral researchers, and then uploaded into the relational database management system by the first author.

Database structure and advantages

The database is implemented in the Open Source PostgreSQL relational database management system (RDBMS) (PostgreSQL Global Development Group, 2009), and includes tables for the assessment metadata, time series values, time series units, and biometrics (a catch-all term for data, such as life history characteristics or BRPs, that are not part of a time series). The entity relationship diagram of the database and its component tables can be found in the Supplementary materials.

RDBMSs form the server back-end to a great many applications of interest to ecologists, including web-clients and GIS software, and have a number of advantages over spreadsheet or flat text file data compilations. First, housing stock assessments in an RDBMS allows multiple users to concurrently access and extract subsets of data in an efficient and reproducible manner. Second, with the development of Application Programming Interfaces (APIs) that allow analytical softwares to directly communicate and extract data from the database, a common data environment is established, independent of one's choice of analytical software (e.g., SAS:SAS ACCESS, Matlab: Matlab/Database, R:RDBI/RODBC, Perl:DBI, etc.). Users familiar with Structured Query Language (SQL) can also query the database directly from their analytical software of choice and the same SQL query will extract the same data through each of these applications. Third, data products tailored to specific projects can be generated and stored as dynamic (continually updated) "views" within the database. These are typically rectangular, spreadsheet-like results of an expansive query of the relevant tables that can be readily read into all commonly-used analytical software. The use of views is, however, greatly advantageous over manipulating spreadsheets or flat text files for importing into a specific analytic software, which runs the risk of losing data integrity (e.g. multiple copies) and becomes impractical with large, non-rectangular datasets and multiple users.

Data integrity and quality control

We have employed several mechanisms to ensure that the database is of high quality. During the data recording process, assessment authors often were contacted to clarify aspects of the assessment or to obtain more detailed data. Time series data presented in figures were, for example, only entered into the database if the exact numbers could be obtained from the assessment or its authors. In cases where multiple models were presented in an assessment without a preferred or best model being denoted, we attempted to ascertain which model was preferred by the stock assessment scientist, but included all model results whenever this was not possible. Once uploaded into the database all stock assessments underwent an additional Quality Assurance/Quality Control (QA/QC) step, to ensure that the entered data replicated that of the original assessment document exactly. This process consisted of creating a QA/QC summary document for each assessment, containing summary details of the stock, a selection of biometrics and ratios for comparison (e.g. current status relative to BRP), and time series plots of the biomass, recruitment, and exploitation trajectories. QA/QC documents were then returned to assessment recorders and an electronic trail of subsequent correspondence was captured using a bug tracking system. Recorders were responsible for checking, and where necessary correcting, their QA/QC documents, after which all corrections were transmitted back to the operational database and a quality controlled flag was inserted to signify the assessment had passed the check. Only assessments that have passed this QA/QC step are available for subsequent analyses.

Links to related databases

To facilitate integration of the RAM Legacy database with 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. Additionally, each stock was assigned to a primary, secondary, and tertiary Large Marine Ecosystem (LME) (NOAA, 1998). LMEs encompass the continental shelves of the world's oceans and represent the most productive areas of the oceans. Open ocean areas beyond the continental shelves are, however, not included. Large, highly migratory oceanic species such as tuna were therefore assigned to new categories "Atlantic High Seas", "Pacific High Seas", "Indian High Seas", and "Subantarctic High Seas".

Database analyses: Assessing the knowledge-base for commercially exploited stocks

We first assess the scope of the stock assessments held in the current version of the RAM Legacy database (Version 1.0, 2010) in terms of institutional contributions, geography, taxonomy, global fisheries, timespan, and ecology. To evaluate the taxonomic scope of the database, we compare the taxonomy of assessed stocks with the diversity of i) all marine fishes (as represented by FishBase), and ii) marine fishes in global fisheries catches (as represented by the SAUP database), and discuss taxonomic biases in species included in catch data and in populations assessed using stock assessments. To determine what fraction of world wild-capture fisheries landings come from assessed stocks, we used the SAUP's average global fisheries catches from the most recent ten years of available data (1995-2004); we also discuss limitations to obtaining assessments for some of the world's major fisheries.

Next, we briefly overview the types of asssessment models and BRPs contained within the stock assessments, and the frequencies of different assessment methods and BRPs overall and by management body. We then evaluate the status of assessed stocks overall, by management body and by trophic level, using standard reference points so that all stocks are referenced to a comparable benchmark. Following Froese and Proelß (2010) and Worm *et al.* (2009), we compare the current status and exploitation rate of stocks relative to their MSY reference points, B_{MSY} and u_{MSY}, respectively.

We do not advocate the use of MSY targets for management, but still report MSY-related BRPs because they can be used to compare multiple stocks. For those assessments that did not contain MSY reference points, but did include total catch ($TC_{i,s}$, $i \in 1, \ldots, n_s$) and total biomass ($TB_{i,s}$, $i \in 1, \ldots, n_s$) time series data, we used a Schaefer surplus production model to estimate total biomass and exploitation rate at

MSY (TB_{MSY_s} and u_{MSY}, respectively). Surplus production of stock s in year t, $P_{s,t}$, is a commonly used measure of stock productivity. The surplus production can be calculated as:

$$P_{s,t} = TB_{s,t+1} - TB_{s,t} + TC_{s,t} \tag{1}$$

where,

$TB_{s,t}$ is the total biomass of stock s in year t

$TC_{s,t}$ is the total catch of stock s in year t

We fit a Schaefer surplus-production model, which is based on a logistic model of population growth to the catch and total biomass time series data. The predicted surplus production in each year in the Schaefer model is given by:

$$\hat{P_{s,t}} = \frac{4mTB_{s,t}}{K} - 4m\left(\frac{TB_{s,t}}{K}\right)^2 \tag{2}$$

where,

m is the maximum sustainable yield

K is the carrying capacity or equilibrium total biomass in the absence of fishing

We estimated the model parameters (m and K) using maximum likelihood in AD Model Builder (ADMB Project, 2009) assuming that the residuals $\epsilon_{s,t} = P_{s,t} - \hat{P_{s,t}}$ were normally distributed. For the Schaefer model, B_{MSY} is simply $0.5K$, and the harvest rate that results in maximum sustainable yield, u_{MSY}, is m/B_{MSY}. Carrying capacity was constrained to be less than twice the maximum observed total biomass.

Finally, we discuss potential applications of the database, point out its limitations and caveats about its use, and outline directions for future development.

All data handling was carried out using a PostgreSQL relational database management system (PostgreSQL Global Development Group, 2009). Statistical analyses and generation of plots were conducted with the R Environment for Statistics and Graphics (Development Core Team, 2009) using the packages RODBC, KernSmooth, gregmisc, xtable, ape, gsubfn, IDPmisc, doBy, and beanplot. The map in Figure 1 was generated using the Generic Mapping Tools (Wessel and Smith, 1991).

Results

Scope of the RAM Legacy database

In total, 324 recent stock assessments for 288 marine fish and 36 invertebrate populations are included in the RAM Legacy database (Version 1.0, 2010).

Management bodies and geography

The database includes stocks assessed by fisheries management bodies in Europe, the United States, Canada, New Zealand, Australia, Russia, South Africa and Argentina (Table 1). Also included are assessments conducted by eight Regional Fisheries Management Organizations (RFMOs), in the Northwest Atlantic, Atlantic, Pacific and Indian Ocean (Table 1). Assessments from the United States comprise by far the most stocks of any country or region (n=139); assessments from the European Union's management body ICES comprise the the second greatest number of stocks (n=63). Whereas nations are responsible for managing all populations within their EEZs, RFMOs typically focus on a certain type of species (e.g. halibut, tunas) or fisheries (e.g. pelagic high seas) within a given area and hence assess a smaller number of stocks.

Most assessments come from North America, Europe, Australia, New Zealand and the High Seas, while few are entered from regions such as Southeast Asia, South America, and the Indian Ocean (outside Australian waters) (Figure 1). Assessments were available for 31 LMEs, with the greatest number of assessed stocks coming from Northeast U.S. Continental Shelf (n=58), California Current (n=35), New Zealand Shelf (n=29), Gulf of Alaska (n=26), Celtic-Biscay Shelf (n=26), East Bering Sea (n=22) and Southeast U.S. Continental Shelf (n=20) (Figure 1).

Taxonomy

157 species from 57 families and 20 orders are included in the database (Figure 2). Five taxonomic orders (Gadiformes (n=67), Perciformes (n=62), Pleuronectiformes (n=53), Scorpaeniformes (n=41) and Clupeiformes (n=36)) account for 80% of available stock assessments. Of these, Perciformes, the most speciose Order of marine fishes are in fact underrepresented in the database (46.04% of all marine fish species vs. 19% of all marine fish assessments), while it is the other four orders that are taxonomically overrepresented: Clupeiformes (2.1% of marine fishes vs. 11% in the database), Gadiformes (3.3% of marine fishes vs. 21% in the database), Pleuronectiformes (4.5% of marine fishes vs. 17% in the database), Scorpaeniformes (8.5% of marine fishes vs. 12% in the database) (Figure 3).

Assessed marine fish stocks in the RAM Legacy database comprise a relatively small proportion of harvested taxa (24% of fish species from the SAUP database) and an even smaller proportion of marine fish biodiversity (1% of fish species in FishBase; Figure 3). In turn, catches from the SAUP database, which come from 649 species and 36 orders

(Figure 3), represent only 5% of the 12339 species and 67% of the 54 different orders present in FishBase (Figure 3).

Timespan

Of the 324 stock assessments, time series data of catch/landings were available for 308 stocks (95%), of SSB for 271 stocks (84%), and of recruitment for 269 stocks (83%). The median lengths of catch/landings, SSB, and recruitment timeseries were 38, 34, and 33 years, respectively. The time period covered by 90% of assessments is: catch/landings (1967-2007), SSB (1972-2007), recruitment (1971-2006), while that covered by 50% of assessments is: catch/landings (1983-2004), SSB (1985-2005), recruitment (1984-2003) (Figure 5).

Stock assessment methodologies and BRPs

In addition to the 324 assessments in the database, indices of relative abundance from scientific surveys are available for an additional 26 stocks. The three most common assessment methods were Statistical catch-at-age/length models (n=164), Virtual Population Analyses (n=90) and Biomass dynamics model (n=45).. .....Need to add a sentence here about the regional differences.... .

The total number and percentage of assessments that reported biomass- or exploitation-based reference points of any sort was 257 (81%) and 222 (69%), respectively. From these assessments, 66 report both a biomass-based and an exploitation-based BRP and appear as solid dots on Figures 6 and 7. Schaefer-derived BRPs add an additional 175 assessments, for a total of 241 assessments used to generate Figure 6. Overall, 58% of assessed stocks are below their biomass-related MSY BRP and 30% are above their exploitation-related MSY BRP. Different management bodies have different overall status of current biomass to BRPs (Figure 7).

Ecology

Assessed species span a range of ecological traits. In terms of their trophic level, we see XXX (Figure 4). The total number and percentage of assessments that reported any life-history information (growth, maturity, fecundity) was 288.

Discussion

The RAM Legacy Database of available stock assessments for the world's marine fisheries, although non-exhaustive, provides a basis to evaluate the existing knowledge-base of exploited marine populations. The stocks comprising the database are predominantly from developed nations with properly identified fisheries management bodies and tend to cover a recent time period. Few assessments extend back beyond 30 years from present. The taxonomic makeup of available assessments is a very limited subset of the accepted taxonomic coverage of marine species worldwide.

Biases

Geographic bias

There are important geographic biases in the amount of assessments entered per LME

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. Similarly, the legal context where fisheries are prosecuted will strongly influence the requirement for conducting stock assessments. In the United States, the Magnuson-Stevens Act defines what stocks are to be monitored and managed, hence a large number of the assessments in the RAM Legacy database are under the jurisdiction of the US National Marine Fisheries Services. 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 It is hoped that readers of this article can assist in correcting these biases by participating in future updates of the RAM Legacy database.

Note Also: from Figure 4 SOFIA 2008 (FAO 2009) - The top 10 wild-caught marine fisheries producer countries are China, Peru, U.S.A., Indonesia, Japan, Chile, India, Russia, Thailand, Philippines. We only have assessments for U.S.A. and Russia (and only 2 for Russia!). Most major fish producing countires do not do assessments or do not make them accessible, still to be decided how to phrase this.

Taxonomic bias

Taxonomic biases in those species that are assessed include ...

Caveats and limitations

Assessment outputs e.g. biomass timeseries, are model 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 often missing from assessments either because they aren't produced by the assessment model (e.g. non-bootstrapped VPA assessments) or the focus of the assessment document was on central tendency (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 (ADMB Project, 2009) and a general 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.

The original database developed by Dr. Myers was used to address a variety of ecological question derived from stock-recruit relationships. This was possible because of the timeseries of stock and recruitment generated in assessment using VPA-type models. With the increasing use of statistical catch-at-age/length models, an underlying stock-recruit relationship is assumed to exist. Estimating the parameters of a stock-recruit relationship using timeseries from such models does not constitute a valid statistical procedure. More generally, the increasing use of Bayesian methods that incorporate prior information poses a challenge for meta-analysis of such model outputs.

Point data are stored in the database with an associated unit, value and year. We expect to also include age-varying and length-varying data such as maturity ogive and age-disaggregated natural mortality in subsequent releases of the RAM Legacy database. In addition to the initial aim of providing reliable access to timeseries information about stocks, we hope to also stimulate research in the relationships of life-history characteristics and their relation to exploitation.

Future Development

It is anticipated that the RAM Legacy database will continue to grow with hitherto unentered stocks and updated assessments for already included stocks. The ultimate goal is to provide a data standard for researchers to use results from multiple regions to assist in their own applied and fundamental research in population ecology, fisheries science, and conservation biology. The development of a standard for assessment reporting would assist in realizing this goal. For example, ICES assessments have a very regular standard, including agreed-upon reference points and regular estimate reporting. 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, associated measures of uncertainty, and commonly-used reference points would streamline the process immensely. 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 collation 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. The RAM Legacy database contains the corresponding species codes to the Sea Around Us Project and FishBase, thus facilitating researchers's use of a global fisheries data "toolkit" to address questions on the relationships between life history attributes and resulting population dynamics in an exploited setting.

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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Tables

Table 1: Number of assessments included in the RAM Legacy database

Country/Ocean	*Management Body*	*Acronym*	*No. stocks*
Australia	Australian Fisheries Management Authority	AFMA	16
Multinational	Commission for the Conservation of Antarctic Marine Living Resources	CCAMLR	1
Argentina	Consejo Federal Pesquero	CFP	6
South Africa	South African national management	DETMCM	14
Canada	Department of Fisheries and Oceans	DFO	22
Multinational	Inter-American Tropical Tuna Commission	IATTC	2
Multinational	International Commission for the Conservation of Atlantic Tunas	ICCAT	10
Multinational	International Council for the Exploration of the Sea	ICES	63
Multinational	Indian Ocean Tuna Commission	IOTC	1
Multinational	International Pacific Halibut Commission	IPHC	1
New Zealand	Ministry of Fisheries	MFish	29
Multinational	Northwest Atlantic Fisheries Organization	NAFO	9
USA	National Marine Fisheries Service	NMFS	139
Russia	Russian Federal Fisheries Agency	RFFA	2
Multinational	South Pacific Regional Fisheries Management Organization	SPRFMO	1
Multinational	Unknown management body	UNKNOWN	1
USA	US state-level management	US State	3
Multinational	Western and Central Pacific Fisheries Commission	WCPFC	4

Stock Rank	*Stock Number*	*Species (Common name, Latin name) or higher taxonomic unit*	*LME*	*In Database?*	*Reason if not included*
1	1	Peruvian anchoveta, *Engraulis ringens*	Humboldt Current	no	3
	2	Marine fishes not identified	South China Sea	no	1
	3	Marine fishes not identified	Bay of Bengal	no	1
2	4	Alaska pollock, *Theragra chalcogramma*	Okhotsk Sea	yes	
3	5	*Ammodytes*	North Sea	yes	
4	6	Atlantic herring, *Clupea harengus*	Norwegian Sea	yes	
5	7	Alaska pollock, *Theragra chalcogramma*	East Bering Sea	yes	
6	8	Capelin, *Mallotus villosus*	Iceland Shelf/Sea	yes	
7	9	European pilchard, *Sardina pilchardus*	Canary Current	yes	
8	10	Japanese anchovy, *Engraulis japonicus*	East China Sea	no	3
9	11	Inca scad, *Trachurus murphyi*	Humboldt Current	yes	
	12	Marine fishes not identified	East China Sea	no	1
10	13	Gulf menhaden, *Brevoortia patronus*	Gulf of Mexico	yes	
	14	Marine fishes not identified	Yellow Sea	no	1
	15	Marine fishes not identified	Indonesian Sea	no	1
11	16	Alaska pollock, *Theragra chalcogramma*	Gulf ofAlaska	yes	
12	17	Argentinean short-finned squid, *Illex argentinus*	Patagonian Shself	no	1

Stock Rank	*Stock Number*	*Species (Common name, Latin name) or higher taxonomic unit*	*LME*	*In Database?*	*Reason if not included*
13	18	Argentine hake, *Merluccius hubbsi*	Patagonian Shelf	yes	
14	19	Japanese anchovy, *Engraulis japonicus*	South China Sea	no	1
15	20	Araucanian herring, *Strangomera bentincki*	Humboldt Current	no	
16	21	Atlantic cod, *Gadus morhua*	Barents Sea	no	
17	22	European sprat, *Sprattus sprattus*	Baltic Sea	yes	
18	23	Atlantic herring, *Clupea harengus*	North Sea	yes	
19	24	Alaska pollock, *Theragra chalcogramma*	Arctic Ocean	no	
	25	Marine fishes not identified	Gulf of Thailand	no	
20	26	Atlantic herring, *Clupea harengus*	Baltic Sea	yes	
21	27	Cape horse mackerel, *Trachurus capensis*	Benguela Current	yes	
22	28	Largehead hairtail, *Trichiurus lepturus*	East China Sea	no	
23	29	Japanese anchovy, *Engraulis japonicus*	Yellow Sea	no	
24	30	European anchovy, *Engraulis encrasicolus*	Black Sea	no	
25	31	Chub mackerel, *Scomber japonicus*	East China Sea	no	

Stock Rank	*Stock Number*	*Species (Common name, Latin name) or higher taxonomic unit*	*LME*	*In Database?*	*Reason if not included*
26	32	Indian oil sardine, *Sardinella longiceps*	Arabian Sea	no	1
	33	*Decapterus*	South China Sea	no	
	34	*Sciaenidae*	Arabian Sea	no	
27	35	Atlantic mackerel, *Scomber scombrus*	North Sea	yes	
28	36	Largehead hairtail, *Trichiurus lepturus*	Yellow Sea	no	
	37	*Merluccius*	Benguela Current	yes	
	38	Marine fishes not identified	Kuroshio Current	no	
29	39	Alaska pollock, *Theragra chalcogramma*	Sea of Japan	no	
30	40	Round sardinella, *Sardinella aurita*	Canary Current	no	

Table 2: The world's forty largest wild-caught fisheries (comprising less than 41% of total global catches, based on average catches 1995-2004 in SAUP database), and the thirty largest fisheries of individual stocks (i.e. fisheries identified to the species level; comprising more than 32% of total global catches), including their LME, whether or not stock assessments for them are included in the RAM Legacy database, and the reason if not included (e.g. 1= no known assessment, 2=assessment is not based on a population dynamics model, 3=assessment inaccessible).

Figures

Figure legends

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

Figure 2. Taxonomic coverage of assessed marine species present in the RAM Legacy 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.

Figure 3. Comparison of the taxonomic diversity of marine species as provided by FishBase (top panel), the coverage of catch data as provided by the Sea Around Us Project (SAUP) database (middle panel) and the RAM Legacy database (bottom panel). To facilitate the identification of the taxonomic groups that are not presented in the catch and assessment data, the FishBase branching pattern of the spoked dendrogram is maintained to generate other two dendrograms.

Figure 4. Mean trophic level of assessed species for overexploited and non-overexploited stocks. Overexploited stocks are those for which the current biomass is below the MSY BRP.

Figure 5. 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 6. Current exploitation rate versus biomass for XXX individual stocks. Exploitation is scaled relative to that which should allow maximum sustainable yield (uMSY); biomass is scaled relative to BMSY. Colors indicate probability of occurrence as revealed by a kernel density smooth function. Solid circles indicate BMSY and uMSY that were obtained directly from assessments; open circles indicate that they were es-

timated from surplus production models.

Figure 7. Current exploitation rate versus biomass for individual stocks grouped by management unit. Plot details as in Figure 6.

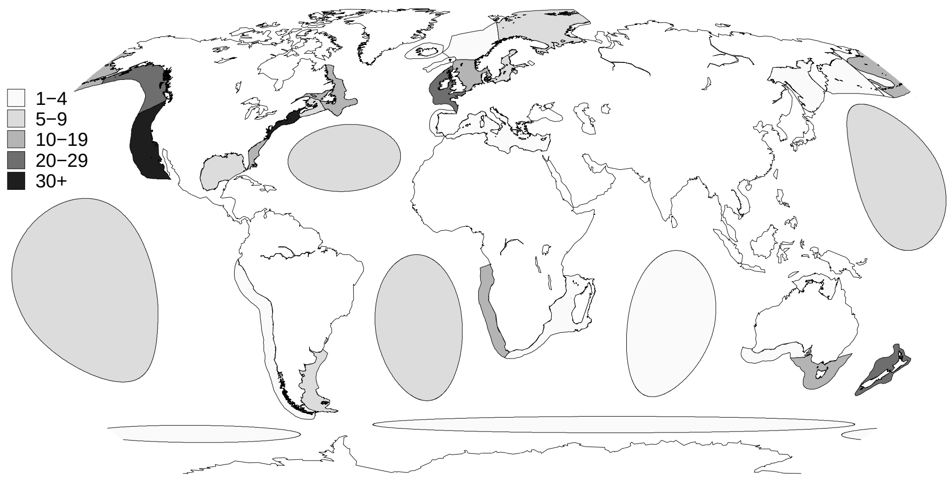
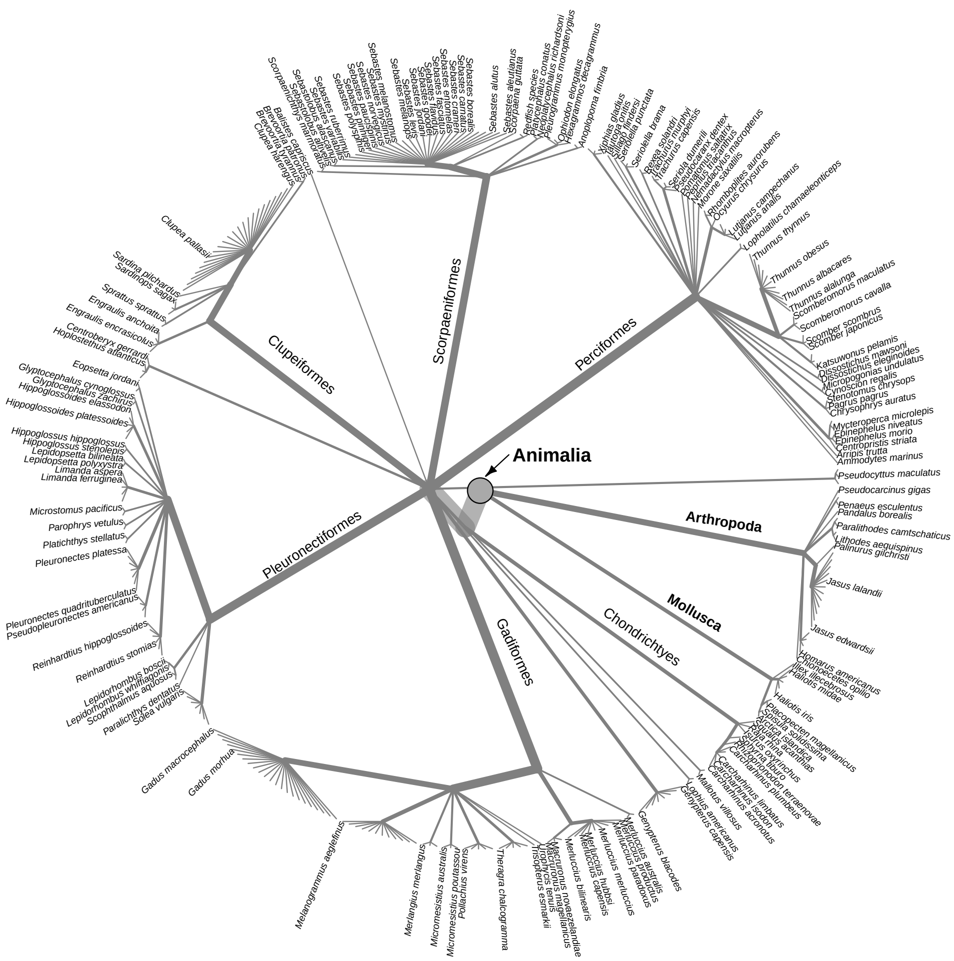


Figure 1:

Figures



Animalia
Arthropoda
Mollusca
Chondrichtyes
Gadiformes
Pleuronectiformes
Clupeiformes
Scorpaeniformes
Perciformes
Pseudocyttus maculatus
Pseudocarcinus gigas
Penaeus esculentus
Pandalus borealis
Paralithodes camtschaticus
Lithodes aequispinus
Palinurus gilchristi
Jasus lalandii
Jasus edwardsii
Homarus americanus
Haliotis iris
Thunnus thynnus
Thunnus obesus
Thunnus albacares
Thunnus alalunga
Scomberomorus maculatus
Scomberomorus cavalla
Scomber scombrus
Scomber japonicus
Katsuwonus pelamis
Dissostichus mawsoni
Dissostichus eleginoides
Micropogonias undulatus
Cynoscion regalis
Stenotomus chrysops
Pagrus pagrus
Chrysophrys auratus
Mycteroperca microlepis
Epinephelus niveatus
Epinephelus morio
Centropristis striata
Arripis trutta
Ammodytes marinus
Clupea pallasii
Sardina pilchardus
Sardinops sagax
Sprattus sprattus
Engraulis anchoita
Engraulis encrasicolus
Centroberyx gerrardi
Hoplostethus atlanticus
Eopsetta jordani
Glyptocephalus cynoglossus
Glyptocephalus zachirus
Hippoglossoides elassodon
Hippoglossoides platessoides
Hippoglossus hippoglossus
Hippoglossus stenolepis
Lepidopsetta bilineata
Lepidopsetta polyxystra
Limanda aspera
Limanda ferruginea
Microstomus pacificus
Parophrys vetulus
Platichthys stellatus
Pleuronectes platessa
Pleuronectes quadrituberculatus
Pseudopleuronectes americanus
Reinhardtius hippoglossoides
Reinhardtius stomias
Lepidorhombus boscii
Lepidorhombus whiffiagonis
Scophthalmus aquosus
Paralichthys dentatus
Solea vulgaris
Gadus macrocephalus
Gadus morhua
Melanogrammus aeglefinus
Merlangius merlangus
Micromesistius australis
Micromesistius poutassou
Pollachius virens
Theragra chalcogramma
Merluccius hubbsi
Merluccius capensis
Merluccius merluccius
Merluccius bilinearis
Genypterus blacodes
Mallotus villosus
Lophius americanus
Sebastes alutus
Sebastes aleutianus
Anoplopoma fimbria
Xiphias gladius
Seriolella brama
Seriolella punctata
Lutjanus campechanus
Lutjanus analis
Lopholatilus chamaeleonticeps
Ocyurus chrysurus
Morone saxatilis

Figure 2:

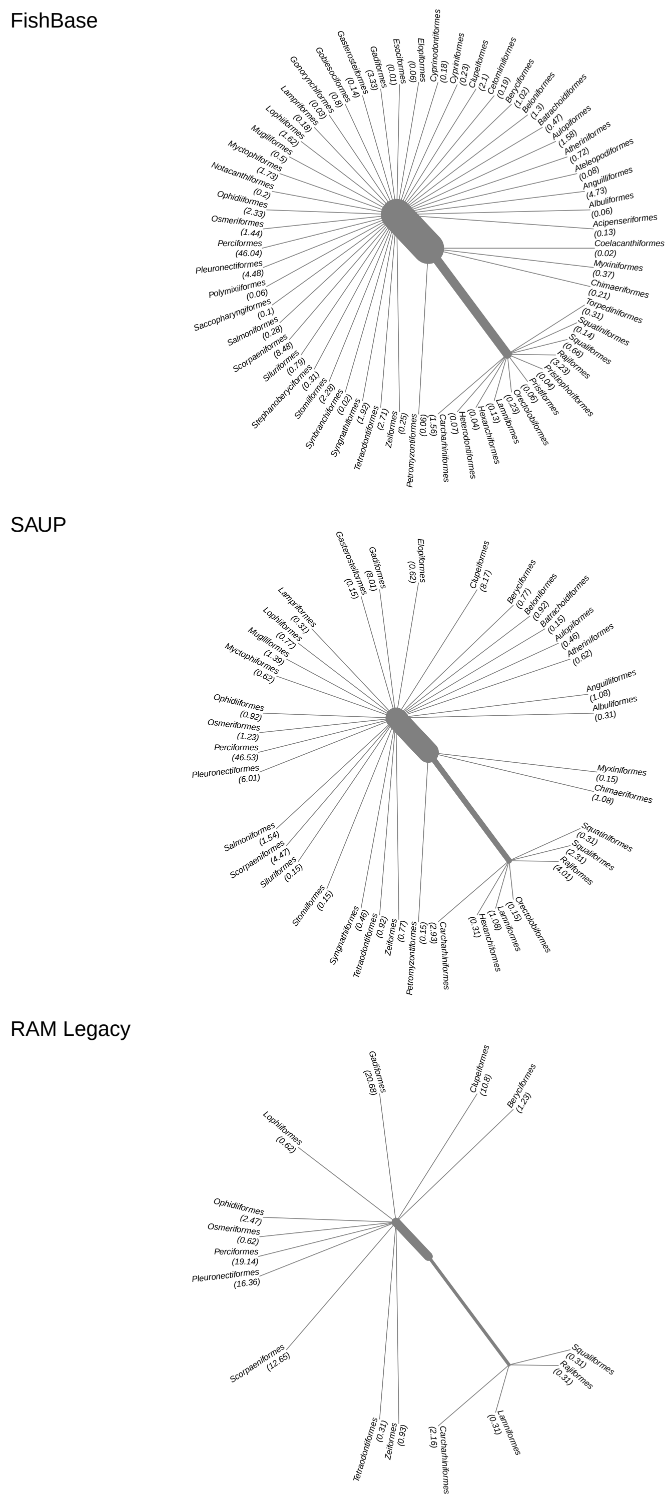
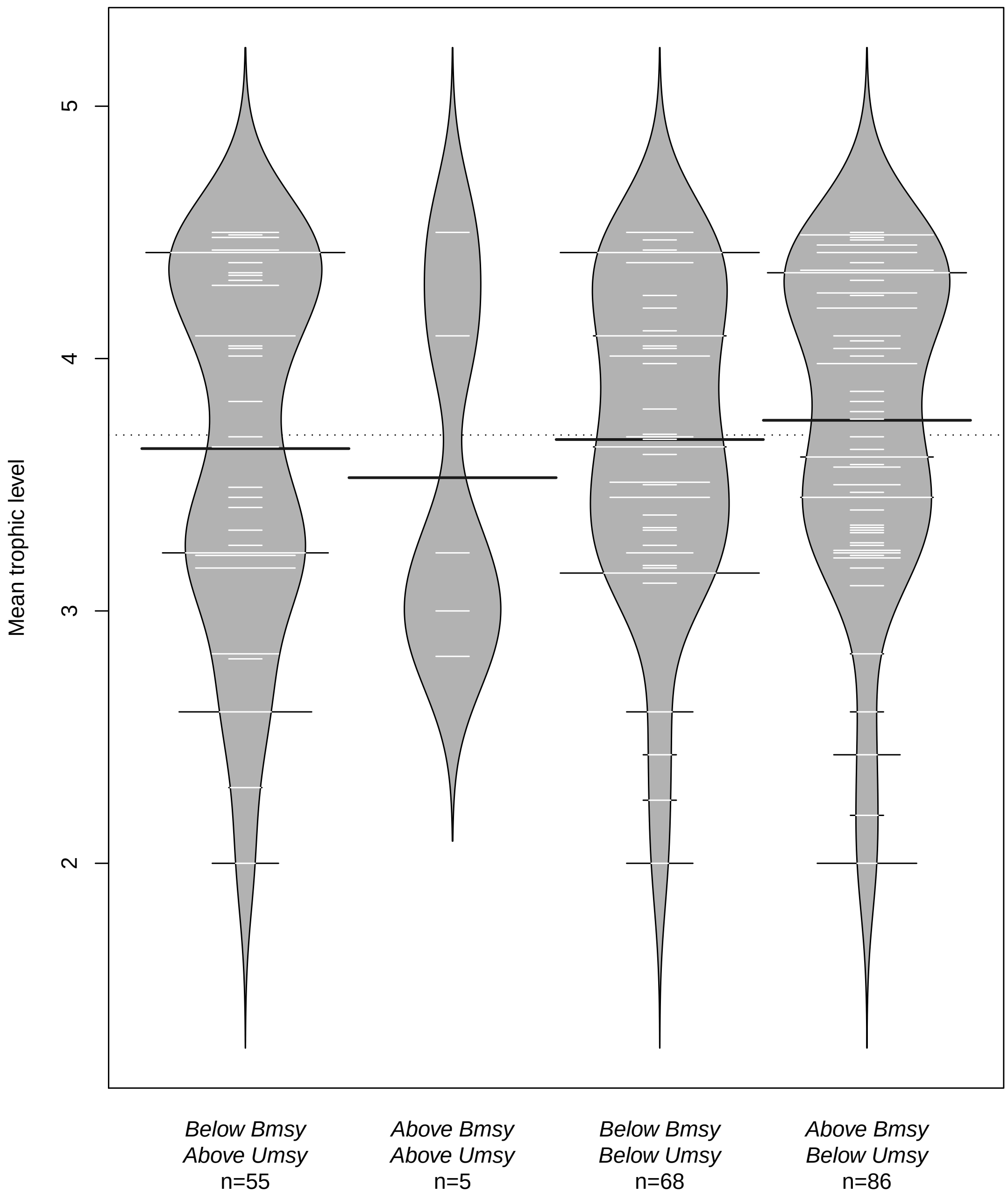


Figure 3:



Mean trophic level
5
4
3
2
Below Bmsy
Above Umsy
n=55
Above Bmsy
Above Umsy
n=5
Below Bmsy
Below Umsy
n=68
Above Bmsy
Below Umsy
n=86

Figure 4:

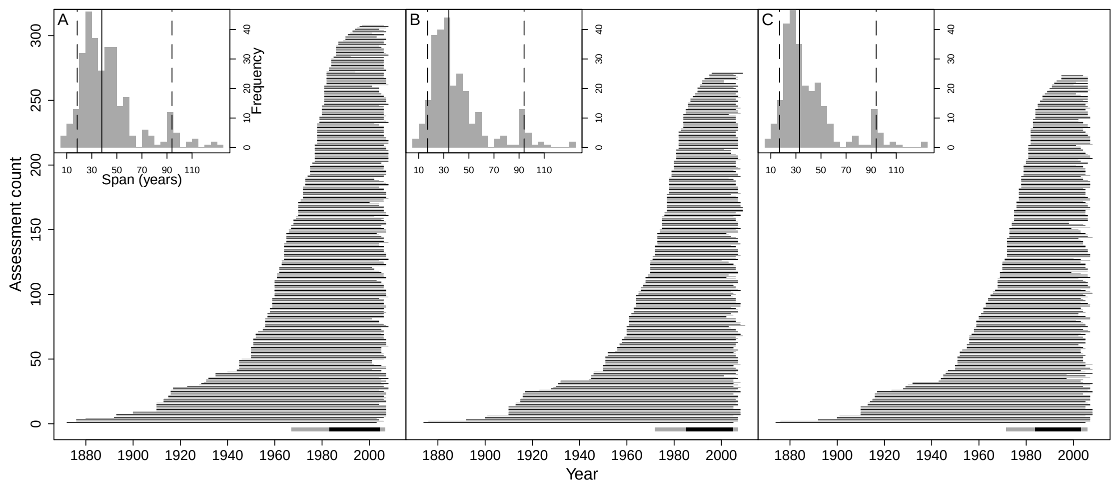


Figure 5:

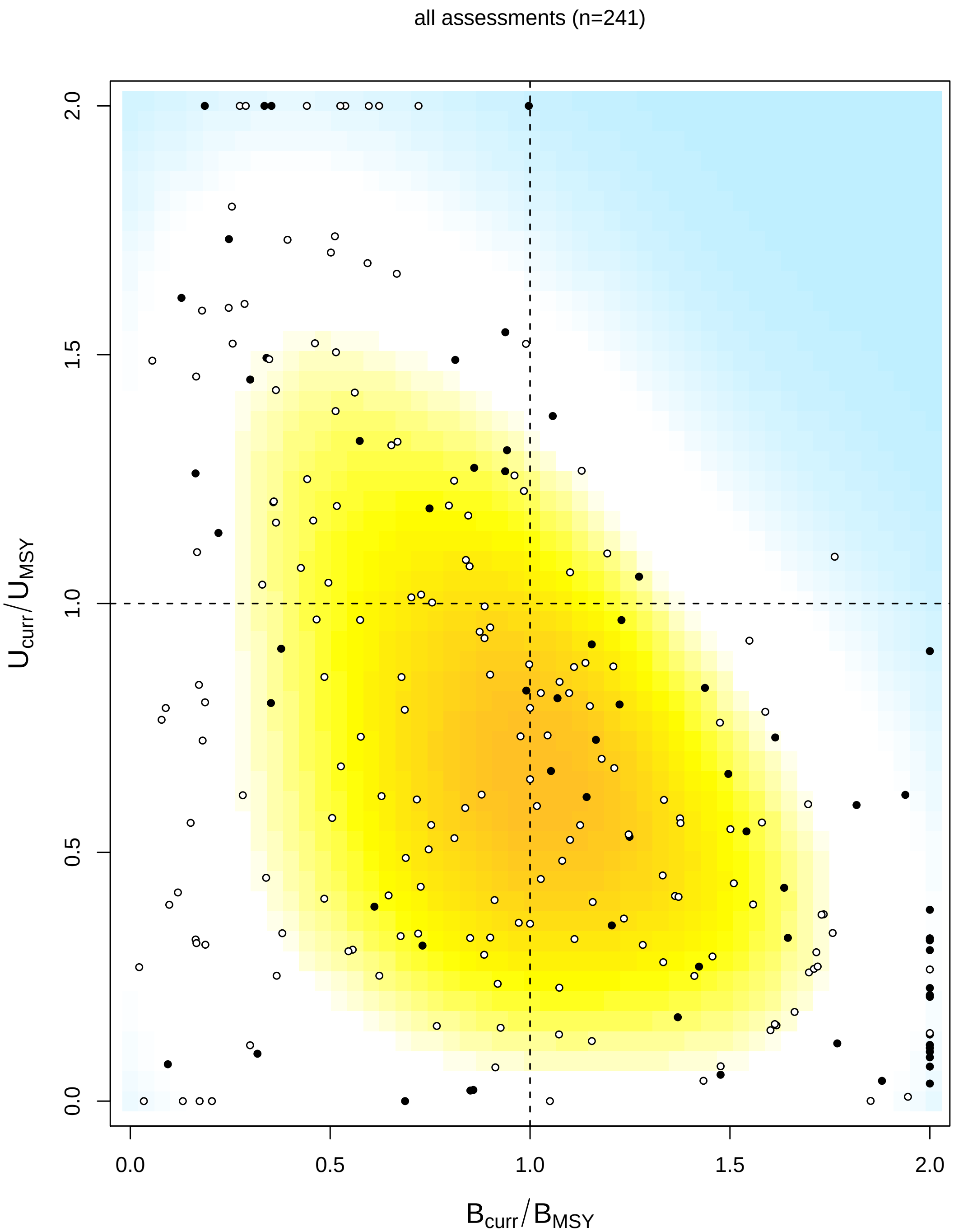

all assessments (n=241)
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
U_{curr}/U_{MSY}
B_{curr}/B_{MSY}

Figure 6:

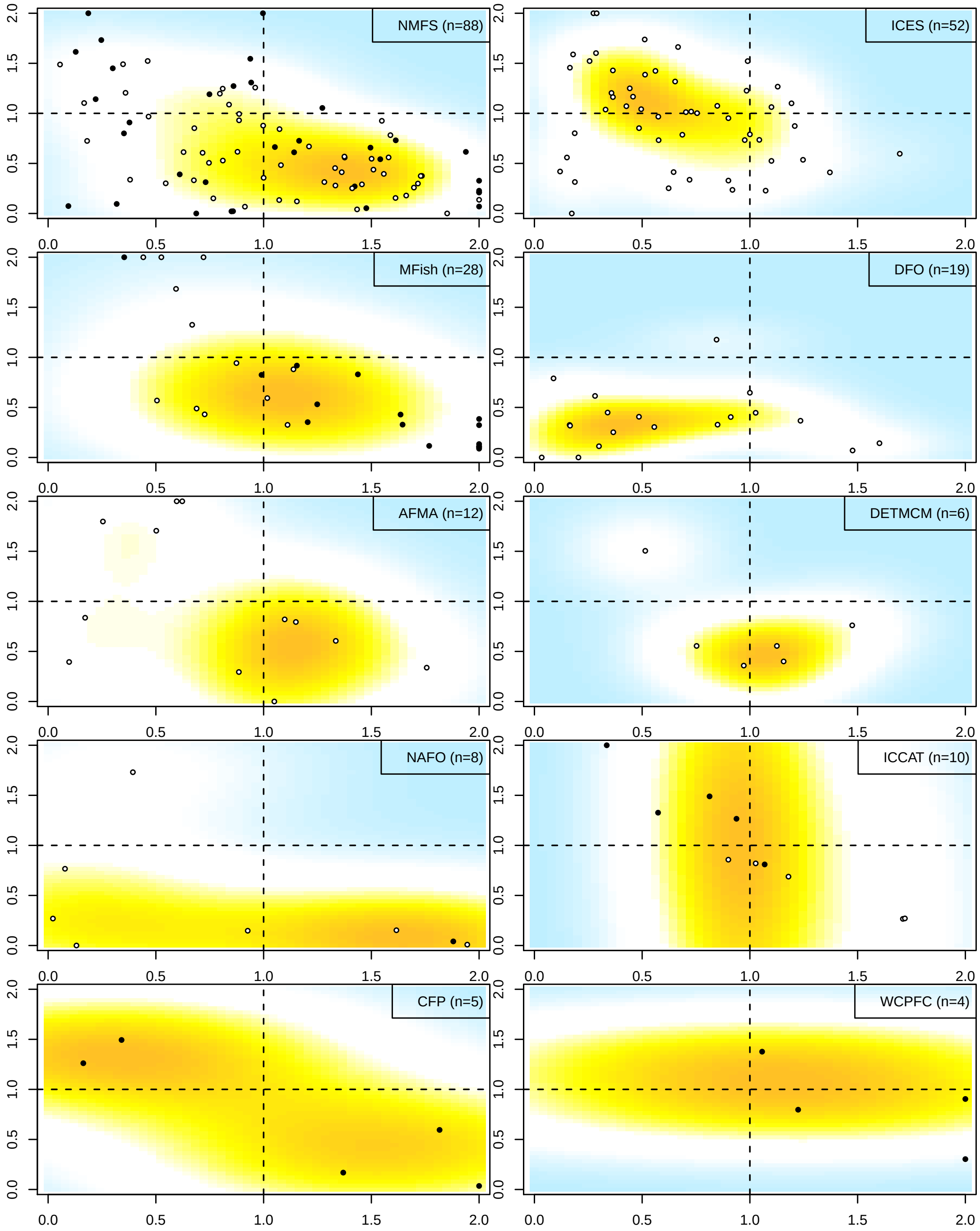

NMFS (n=88)
ICES (n=52)
MFish (n=28)
DFO (n=19)
AFMA (n=12)
DETMCM (n=6)
NAFO (n=8)
ICCAT (n=10)
CFP (n=5)
WCPFC (n=4)
0.0
0.5
1.0
1.5
2.0

Figure 7: