

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

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

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

6 Suggested Running Title: A new global stock assessment database

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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, research surveys, and sophisticated population dynamics models that integrate many sources of information. Previous evaluations of the state of global fisheries have used catch 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substantial syntheses of stock status; however its focus was on stock-recruitment relationships and it is now 15 years out of date. To facilitate contemporary syntheses, we have assembled a new database, the RAM Legacy Database, of the most intensively studied commercially exploited marine fish stocks, including 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 this database and use it to evaluate the knowledge-base for assessed marine species. Globally, assessments were assembled for 324 stocks (288 fish species representing 45 families, and 36 invertebrate species representing 12 families), including 8 of the world’s 10 largest fisheries. Assessments were obtained from 18 national and international management institutions, with most coming from North America, Europe, Australia, New Zealand and the High Seas. Overall, 58% of stocks are below B_{msy} , and 30% have exploitation levels above U_{msy} . Assessed marine fish stocks comprise a relatively small proportion of harvested taxa (24%), and an even smaller proportion of marine fish biodiversity (1%).

Keywords: marine fisheries, meta-analysis, population dynamics models, relational database, stock assessment, synthesis.

34 Introduction

35 Marine wild capture fisheries provide more than 80 million tons of fisheries products
36 (both food and industrial) per year and employ 43.5 million people (wild capture and
37 aquaculture, (FAO, 2009b)). At the same time, fishing has been recognized as having
38 one of the most widespread human impacts in the world’s oceans (Halpern *et al.*, 2008),
39 and the Food and Agricultural Organization of the United Nations (FAO) estimates
40 that two-thirds of fish stocks globally are fully exploited or overexploited (FAO, 2009b).
41 While many fisheries have reduced exploitation rates to levels that should in theory
42 promote recovery, overfishing continues to be a serious global problem (Worm *et al.*,
43 2009). Fishery managers are asked to address multiple competing objectives, including
44 maximizing yields, ensuring profitability, reducing bycatch, and minimizing the risk
45 of overfishing. Given the enormous social and economic costs (Rice *et al.*, 2003) and
46 ecosystems consequences (Frank *et al.*, 2005; Myers *et al.*, 2007) of collapsed fisheries,
47 it is imperative that we are able to quickly learn from successful and failed fisheries
48 from around the world.

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

60 The global databases of fishery landings compiled by FAO (FAO, 2009a) and syn-
61 thesized by the Sea Around Us project (Watson *et al.*, 2004) have proven to be valuable

resources for understanding the status of fisheries worldwide; however, catch data alone can be misleading when used as a proxy for stock size. Many papers have used these data 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). Standardizing catch by the amount of fishing effort (catch-per-unit-of-effort, CPUE) is an improvement, particularly when these data are modeled to account for spatial, temporal, and operational factors affecting the CPUE, but CPUE can still be an unreliable index of relative abundance since it is difficult to account for all relevant factors (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 coming from different fisheries and/or from fishery-independent surveys. Because they integrate across multiple sources of information, stock assessment models should provide a more accurate picture of changes in abundance than catch data alone (Sibert *et al.*, 2006), the trade-off being that their complexity renders them difficult for non-experts to evaluate. Without a current and comprehensive database of stock assessments, however 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 the late Ransom A. 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; biological reference points were however largely absent. The original

91 release version of the Myers database (Myers *et al.*, 1995b) included spawning stock
 92 size and recruitment time series for 274 stocks representing 92 species as well as fishing
 93 mortality rates time series for 144 stocks. The number of entered stocks grew to ap-
 94 proximately 642 stocks (509 with at least one SR pair) over the period from 1995-2005.
 95 Note that anadromous fishes of the family Salmonidae comprised 290 assessments in the
 96 original database. The assessment results collated by Dr. Myers were used to: 1) deci-
 97 sively answer the question of whether recruitment shows any relationship to spawning
 98 stock size (Myers and Barrowman, 1996), 2) investigate potential depensation in stock-
 99 recruitment relationships (Myers *et al.*, 1995a; Liermann and Hilborn, 1997; Garvey
 100 *et al.*, 2009), 3) discover generalities in the annual reproductive rates of fishes (Myers
 101 *et al.*, 1999, 2002b), 4) investigate density-dependence in juvenile mortality (Myers,
 102 2001; Minto *et al.*, 2008), 5) develop informative Bayesian priors on steepness (Myers
 103 *et al.*, 1999, 2002a; Dorn, 2002), and 6) examine patterns of collapse and recovery in
 104 exploited fish populations (Hilborn, 1997; Hutchings, 2001a,b) .

105 Although the original Myers database (Myers *et al.*, 1995b) was critical for moti-
 106 vating comparative analyses in fisheries science, most of the stocks are now 15 years
 107 out of date. For stocks that were depleted in 1995, the past 15 years include valu-
 108 able observations at low stock size or of a recovering population, both of which are
 109 critical for estimating population dynamics parameters such as the behaviour of the
 110 stock-recruitment relationship near the origin. In addition, there have been numerous
 111 improvements in stock assessment methodologies (including important advances in sta-
 112 tistical catch-at-age or catch-at-length models) and assessments have been conducted
 113 for the first time for many species.

114 Meta-analyses of fishery status also have been hampered by the lack of a global as-
 115 sessment database containing biological reference points (BRPs, e.g., the total/spawning
 116 biomass and fishing mortality rate that produce Maximum Sustainable Yield (MSY),
 117 B_{MSY} and F_{MSY}). Knowledge of BRPs is important if stocks are to be managed for high
 118 yields that can be sustained over time (Mace, 1994). Without information on reference
 119 points, previous analyses of stock assessments or catch data have instead relied upon

120 non-biological thresholds to define fishery status, such as the greatest 15-year decline
121 (Hutchings and Reynolds, 2004) or 10 percent of maximum catch (Worm *et al.*, 2006).
122 Ad hoc reference points based on some fraction of the maximum of a time series also
123 have undesirable statistical properties and can result in false collapses when applied to
124 inherently variable time series of catch or abundance (Wilberg and Miller, 2007; Branch,
125 2008). Complicating comparisons of fishery status is the fact that different BRPs are
126 used in different parts of the world and even the same BRP can be used in a different
127 manner, for example, as a target or as a limit.

128 Here we present a new global database of stock assessments for commercially ex-
129 ploited marine fish populations. The database is an update and extension of that
130 developed by Ransom A. Myers, and is named the RAM Legacy database in honour of
131 his pioneering contribution. This effort is the first global stock assessment database to:

- 132 1. Use a formal relational database structure;
- 133 2. Use source control software to organise release versions;
- 134 3. Include metadata related to the geographic location of the stock, the type of
135 assessment model used, and the original source document for the assessment data;
- 136 4. Include biological reference points, in addition to stock-specific life history infor-
137 mation.

138 We use the new RAM Legacy database (Version 1.0, 2010) to evaluate the knowledge-
139 base for commercially exploited marine populations in terms of institutional contri-
140 butions, geography, taxonomy, ecology, timespan, stock assessment methodologies and
141 BRPs. We compare the database’s taxonomic coverage to that of global fisheries catches
142 and to global fish diversity. We then evaluate the status of assessed stocks globally, and
143 by management body, referencing all stocks to a comparable benchmark. Finally, we
144 discuss biases in the knowledge base for assessed marine species, highlight potential ap-
145 plications of the database, point out its caveats and limitations, and outline directions
146 for future development.

147 **Methods**

148 *The RAM Legacy database*

149 The RAM Legacy database is a global relational database designed and developed
150 to store data from all current and accessible population dynamics model-based fisheries
151 stock assessments for marine fish and invertebrate populations. Time series of spawning
152 stock biomass (SSB), total biomass (TB), recruits (R), total catch (TC) or landings
153 (TL), and fishing mortality (F) from individual stock assessments form the core of
154 the database. Apart from catch/landings, these time series are not raw data, but
155 rather the output of population dynamics models; depending on the type of assessment
156 model not all of these time series were available for every stock. The database also
157 contains details about the time series data, including the age and sex of spawners, age
158 of recruits, and the ages used to compute the fishing mortality, as well as BRPs and
159 some life history information (e.g. growth parameters, age and length at 50% maturity
160 and natural mortality rate). Metadata for each stock assessment consists of taxonomic
161 information about the species and the geographic location of the stock (detailed in
162 “Links to related databases”), the management body that conducted the assessment,
163 the assessment methodology, the reference for the stock assessment document, the name
164 of the recorder entering the assessment data, and the date the assessment was entered.
165 Some assessments, particularly those for invertebrates, were based only on CPUE time
166 series rather than population dynamics models. While we included these in the database
167 (n=26), the database description and analyses presented here focus on those stocks
168 assessed using population dynamics models.

169 Over the past two and a half years, we have employed a variety of search methods
170 in an attempt to obtain all recent fisheries stock assessments. Publicly available stock
171 assessment reports available from the internet were the primary data source. These
172 reports were obtained either from the website of the relevant management agency or
173 directly from stock assessment scientists. Other assessments were obtained from the
174 primary literature and through personal contacts at fisheries management agencies.

175 Significant contributions were also made by the other members of the National Cen-
176 ter for Ecological Analysis and Synthesis (NCEAS) working group “Finding common
177 ground in marine conservation and management”. Relevant assessment data were first
178 transferred into a standardized spreadsheet template by a number of recorders, includ-
179 ing ourselves, assessment authors, our NCEAS collaborators, and associated graduate
180 students and postdoctoral researchers, and then uploaded into the relational database
181 management system by the first author.

182 *Database structure and advantages*

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

189 RDBMSs form the server back-end to many applications of interest to ecologists,
190 including web-clients and GIS software, and have a number of advantages over spread-
191 sheet or flat text file data compilations. First, housing stock assessments in an RDBMS
192 allows multiple users to concurrently access and extract subsets of data in an efficient
193 and reproducible manner. Second, with the development of Application Programming
194 Interfaces (APIs) that allow analytical softwares to directly communicate and extract
195 data from the database, a common data environment is established, independent of
196 one’s choice of analytical software (e.g., SAS:SAS ACCESS, Matlab: Matlab/Database,
197 R:RDBI/RODBC, Perl:DBI, etc.). Users familiar with Structured Query Language
198 (SQL) can also query the database directly from their analytical software of choice
199 and the same SQL query will extract the same data through each of these applica-
200 tions. Third, data products tailored to specific projects can be generated and stored as
201 dynamic (i.e., continually updated) “views” within the database. These are typically
202 rectangular, spreadsheet-like results of an expansive query of the relevant tables that

203 can be readily read into all commonly-used analytical software. The use of views is ad-
204 vantageous over manipulating spreadsheets or flat text files for importing into a specific
205 analytic software, which runs the risk of losing data integrity (e.g. multiple copies) and
206 becomes impractical with large, non-rectangular datasets and multiple users.

207 *Data integrity and quality control*

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

228 *Links to related databases*

229 To facilitate integration of the RAM Legacy database with related databases, such
230 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, a matching SAUP taxon code, and taxonomic information from the Integrated Taxonomic Information System (ITIS) (<http://www.itis.gov>). Additionally, each stock was assigned to a primary (and in some cases 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 in the LME classification. 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”.

Assessing the knowledge-base for commercially exploited stocks

We assess the knowledge-base for commercially exploited stocks, as represented by the RAM Legacy database, using a variety of metrics. 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 species available from the SAUP database), and discuss taxonomic biases in species included in catch data and in populations assessed using stock assessments. We evaluate the ecological scope of assessed stocks in terms of age at sexual maturity as reported in the assessments, and trophic level of those assessed stocks as reported in FishBase. We overview the types of assessment models used, and BRPs estimated, for all stock assessments and by management body. 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. Comparisons between assessments and catch data at a regional level are hampered by the geographic mismatch between stocks and FAO statistical areas or the SAUP’s Large Marine Ecosystems.

259 *Assessing the status of commercially exploited marine stocks*

260 We evaluate the status of assessed stocks overall and by management body, using
 261 standard reference points so that all stocks are referenced to a comparable benchmark.
 262 Following Froese and Proelß (2010) and Worm *et al.* (2009), we compare the current
 263 biomass and exploitation rate of stocks relative to their MSY reference points, B_{MSY}
 264 and U_{MSY} , respectively.

265 We do not advocate the use of MSY targets for management, but still report MSY-
 266 related BRPs because they are the most commonly estimated BRP and can be used
 267 to compare multiple stocks. For those assessments that did not contain MSY reference
 268 points, but did include total catch ($TC_{i,s}$, $i \in 1, \dots, n_s$) and total biomass ($TB_{i,s}$,
 269 $i \in 1, \dots, n_s$) time series data, we used a Schaefer surplus production model to estimate
 270 total biomass and exploitation rate at MSY (TB_{MSY_s} and u_{MSY} , respectively). Surplus
 271 production of stock s in year t , $P_{s,t}$, is a commonly used measure of stock productivity,
 272 representing the amount of catch that can be taken while maintaining the biomass at
 273 a constant size, and can be calculated as:

$$P_{s,t} = TB_{s,t+1} - TB_{s,t} + TC_{s,t} \quad (1)$$

274 where,

275 $TB_{s,t}$ is the total biomass of stock s in year t

276 $TC_{s,t}$ is the total catch of stock s in year t

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

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

280 where,

281 m is the maximum sustainable yield, equal to $rK/4$

282 K is the carrying capacity or equilibrium total biomass in the absence of fishing
283 (Hilborn and Walters, 1992)

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

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

291 Statistical analyses and plot generation were conducted with the R Environment for
292 Statistics and Graphics (Development Core Team, 2009) using the packages *RODBC*
293 (Ripley *et al.*, 2009), *KernSmooth* (original by Matt Wand. R port by Brian Ripley.,
294 2009), *xtable* (Dahl, 2009), *ape* (Paradis *et al.*, 2004), *gsubfn* (Grothendieck, 2010),
295 *IDPmisc* (Ruckstuhl *et al.*, 2009), and *doBy* (with contributions from Kevin Wright
296 and Leidi., 2010). Figure 1 was generated using the Generic Mapping Tools (Wessel
297 and Smith, 1991).

298 Results

299 *The knowledge-base for commercially-exploited marine stocks*

300 In total, 324 recent stock assessments for 288 marine fish and 36 invertebrate popula-
301 tions are included in the RAM Legacy database (Version 1.0, 2010; Table S1). Together
302 these comprise time series of catch/landings for 308 stocks (95%), SSB estimates for
303 271 stocks (84%), and recruitment estimates for 269 stocks (83%) (Table S1).

304 *Management bodies and geography*

305 Stock assessments are derived from fisheries management bodies in Europe, the
306 United States, Canada, New Zealand, Australia, Russia, South Africa and Argentina
307 (Table 1). Also included are assessments conducted by eight Regional Fisheries Manage-
308 ment Organizations (RFMOs), in the Northwest Atlantic, Atlantic, Pacific and Indian
309 Ocean (Table 1). Assessments from the United States comprise by far the most stocks
310 of any country or region (n=139); assessments from the European Union's manage-
311 ment body, the International Council for the Exploration of the Seas (ICES), comprise
312 the the second greatest number of stocks (n=63). Whereas nations are responsible for
313 managing all populations within their EEZs, RFMOs typically focus on a certain type
314 of species (e.g. halibut, tunas) or fisheries (e.g. pelagic high seas) within a given area
315 and hence assess a smaller number of stocks.

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

323 *Taxonomy*

324 Assessments for 157 species from 57 families and 20 orders are included in the
325 database (Figure 2). Five taxonomic orders (Gadiformes (n=67), Perciformes (n=62),
326 Pleuronectiformes (n=53), Scorpaeniformes (n=41) and Clupeiformes (n=36)) account
327 for 80% of available stock assessments. Of these, Perciformes, the most speciose Order
328 of marine fishes are in fact underrepresented in the database (46.04% of all marine fish
329 species vs. 19% of all marine fish assessments), while the other four orders are taxonom-
330 ically overrepresented: Clupeiformes (2.1% of marine fishes vs. 11% in the database),
331 Gadiformes (3.3% of marine fishes vs. 21% in the database), Pleuronectiformes (4.5%
332 of marine fishes vs. 17% in the database), Scorpaeniformes (8.5% of marine fishes vs.
333 12% in the database) (Figure 3).

334 Assessed marine fish stocks in the RAM Legacy database comprise a relatively small
335 proportion of harvested taxa (24% of fish species from the SAUP database) and an even
336 smaller proportion of marine fish biodiversity (1% of fish species in FishBase; Figure 3).
337 In turn, catches from the SAUP database, which come from 649 species and 36 orders
338 (Figure 3), represent only 5% of the 12339 species and 67% of the 54 different orders
339 present in FishBase (Figure 3). The diversity of harvested marine invertebrates is clearly
340 underrepresented in the stock assessment database and likely in stock assessments in
341 general.

342 *Ecology*

343 Assessed species span a range of ecological traits. Some life-history information
344 (e.g. growth, maturity, fecundity) is available for 288 of the collated assessments. In
345 some cases, this information is derived from biological studies, while in other cases
346 life-history parameters represent model assumptions (e.g., natural mortality = 0.2) or
347 model estimates. The trophic level of assessed species ranged from 2 to 4.5 with a mean
348 of 3.7, with no apparent relationship between trophic level and stock status (Figure 4).

349 *Timespan*

350 The median lengths of catch/landings, SSB, and recruitment timeseries were 38,
351 34, and 33 years, respectively (Figure 5). The time period covered by 90% of assess-
352 ments is: catch/landings (1967-2007), SSB (1972-2007), recruitment (1971-2006), while
353 that covered by 50% of assessments is: catch/landings (1983-2004), SSB (1985-2005),
354 recruitment (1984-2003) (Figure 5).

355 *Stock assessment methodologies and BRPs*

356 The three most common assessment methods were Statistical catch-at-age/length
357 models (n=164), Virtual Population Analyses (n=90) and Biomass dynamics model
358 (n=45). Regionally, Virtual Population Analysis (VPA) is still the most common as-
359 sessment model for ICES (71% of 63 assessments), DFO (59% of 22 assessments) and
360 Argentina’s CFP (83% of 6 assessments), whereas statistical catch-at-age and -length
361 models are more common for NMFS (66% of 139 assessments), AFMA (81% of 16
362 assessments) and MFish (76% of 29 assessments).

363 Biomass- or exploitation-based reference points were available for 257 (81%) and 222
364 (69%) assessments, respectively. The most commonly reported biomass-based BRPs
365 relate to biomass at MSY (e.g. B_{msy}), to “limit” biomass (e.g. B_{lim}) and to “precau-
366 tionary approach” biomass (e.g. B_{pa}). Biomass and exploitation of US stocks under the
367 management of NMFS must follow MSY-based reference points whereas other fisheries
368 agencies use different BRPs.

369 *Global Fisheries*

370 Assessments were available for 8 of the 10 largest fisheries for individual fish stocks
371 globally (Table 2). Assessments for Peruvian anchoveta, the world’s largest fishery, and
372 for Japanese anchovy in the East China Sea (the eighth largest species for an individual
373 stock, and tenth overall) were not accessible. Looking more broadly, the database
374 contains assessments for 16 of the 30 largest fisheries for individual fish stocks globally,
375 and 17 of the 40 largest fisheries globally (including those recorded at lower taxonomic
376 resolutions) (Table 2). Many of the fisheries not included in the RAM Legacy database,

377 especially those recorded in the SAUP database as “Marine fishes not identified” (n=7),
 378 occur in developing countries and have no known formal stock assessment conducted
 379 for them. From a national perspective, assessments are only included for 2 of the top
 380 10 wild-caught marine fisheries producing nations, U.S.A. and Russia (FAO, 2009b),
 381 with only two assessments from the latter. We were unable to obtain any assessments
 382 from the other top 10 countries: China, Peru, Indonesia, Japan, Chile, India, Thailand,
 383 Philippines (FAO, 2009b).

384 *The status of commercially exploited marine stocks*

385 To evaluate stock status, we single out stocks where both a biomass BRP and an ex-
 386 ploitation BRP are available. Of the 241 stocks presented in Figure 6, 66 come directly
 387 from assessments and 175 come from surplus production model fits. To identify poten-
 388 tial biases arising from using BRPs derived from surplus production models we com-
 389 puted a contingency table of status classification for stocks that have both assessment-
 390 and Schaefer-derived BRPs (Table S2). Surplus production models correctly classified
 391 ratios of current biomass to BRPs in 71% of cases (for 67 of 95 assessments) and 63%
 392 of cases for exploitation BRPs (for 37 of 59 assessments).

393 Overall, 58% of stocks are estimated to be below their biomass-related MSY BRP,
 394 that is $B_{curr} < B_{msy}$, and 30% are above their exploitation-related MSY BRP, $U_{curr} >$
 395 U_{msy} (n=241 stocks total; Figure 6). Of the stocks for which biomass is currently es-
 396 timated to be below B_{msy} , 53% have had their exploitation rate reduced below U_{msy} ,
 397 suggesting potential for recovery (Figure 6). The remaining 47% of these stocks how-
 398 ever, still have excessive exploitation rates (Figure 6). Encouragingly, 42% of all stocks
 399 are estimated to be above B_{msy} , and 94% of the stocks above B_{msy} also have $U_{current}$
 400 below U_{msy} .

401 The status of exploited marine stocks, as estimated from biomass- and exploitaion-
 402 BRPs, varied widely depending on the management body (Figure 7). Most European
 403 stocks (managed by ICES) have biomasses less than B_{msy} (79%), and over half of these
 404 stocks (61%) still have exploitation rates exceeding U_{msy} . Canadian stocks (managed

405 by DFO) also had low biomass ($79\% < B_{msy}$), but all but one of these has had its
 406 exploitation rate reduced below U_{msy} . In contrast, about half (49%) of U.S. stocks
 407 (managed by NMFS) are estimated to still be above B_{msy} , and of the 45 stocks that are
 408 below B_{msy} 58% have exploitation rates below U_{msy} (Figure 7). In the New Zealand
 409 and Australian waters, stocks managed by MFish and AFMA are above B_{msy} in 61%
 410 and 42% of cases, respectively. For the stocks grouped as “Atlantic” in Figure 7 we
 411 found that 5 of the 10 ICCAT stocks and 5 of the 10 of NAFO stocks were below B_{msy}
 412 .

413 Discussion

414 *The knowledge-base and status of commercially exploited marine stocks*

415 The RAM Legacy Database provides detailed time series and point data from avail-
416 able stock assessments for the world’s industrial marine fisheries, thus providing a basis
417 for evaluating the existing knowledge-base and current status of these fisheries. Acces-
418 sible stock assessments are predominantly from developed nations in north-temperate
419 regions, and tend to cover only the past few decades, typically a significantly shorter
420 period than that for which the stock has been exploited. The taxonomic makeup of
421 available assessments is a very limited subset of the accepted taxonomic coverage of
422 marine species worldwide, and of globally exploited species. Most notably (with the
423 exception of tunas), assessment-based knowledge is not available for coral reef and other
424 tropical fishes. Inshore (e.g. estuarine species) and anadromous populations are also
425 noteworthy in their absence (as a result of our focus on federally or internationally
426 managed marine species) and, as such, any assessment of global status of exploited
427 populations must be interpreted only for that subset of exploited species for which
428 assessments are present in the database.

429 In its latest State of the World Fisheries and Aquaculture (FAO, 2009b), the FAO
430 reports that 20% of stocks are underexploited, 52% are fully exploited, 19% are over-
431 exploited and 1% is recovering from depletion. The ambiguous classification of stocks
432 as “underexploited”, “fully exploited” and “overexploited” makes comparisons of our
433 results with those from the FAO difficult. Our estimates are that almost 60% of stocks
434 are below the biomass reference point that maximises their yield. Almost half of stocks
435 that are below B_{msy} still experience exploitation rates that are above those that would
436 maximise yield. Our results also provide evidence that appropriate fisheries manage-
437 ment measures can curtail over-exploitation and that stocks can recover. For depleted
438 stocks, recovery requires strongly articulated legislation, potentially difficult short- to
439 medium-term regulations to decrease fishing mortality, protection of habitat through
440 area closures and recovery targets with well-defined timelines. For stocks that exist in

441 areas beyond national jurisdiction, nation members of various Regional Fisheries Man-
442 agement Organisations must treat international regulations as bindings agreements that
443 must be fulfilled.

444 *Biases in the knowledge-base for commercially exploited marine stocks*

445 *Geographic bias*

446 Bias in the geographic scope of the RAM Legacy database (relative to that of all
447 fisheries globally) may arise for several reasons, all of which vary geographically in their
448 prevalence: 1. an assessment is not conducted on a stock; 2. it is not possible to access
449 the assessment; or 3. the non-exhaustive collation we undertook overlooked the assess-
450 ment. Whether an assessment is conducted for a given stock depends upon a multitude
451 of factors, including the economic value of the stock, the availability of fiscal resources
452 to collect the data required for an assessment (which frequently includes conducting
453 fisheries-independent research surveys) and the expertise to conduct assessments. In
454 general, conducting stock assessments is a costly endeavour that is restricted to wealthy
455 fishing nations. The legal context where fisheries are prosecuted can also strongly in-
456 fluence the requirement for conducting stock assessments. In the United States, the
457 Magnuson-Stevens Act defines which stocks are to be monitored and managed, hence a
458 large number of the assessments in the RAM Legacy database are under the jurisdiction
459 of the US National Marine Fisheries Services. How accessible assessments are for entry
460 depends upon the transparency and access policies of the relevant management agen-
461 cies, which also varies geographically. Our search for assessments could also give rise
462 to geographic biases, as concerted collation efforts have only been conducted in those
463 known assessment-rich regions. It is hoped that readers of this article can assist in cor-
464 recting these biases by participating in future updates of the RAM Legacy database,
465 and that the development of this database will encourage greater transparency amongst
466 fishing nations.

467 *Taxonomic bias*

468 Related to geographic bias is the taxonomic bias in those species that are known,
469 caught and assessed. At a broad level the Gadiformes and Clupeiformes occupy dis-
470 proportionate taxonomic representation in the catch compared to overall species occur-
471 rence (Figure 3, panels a and b). Taxonomic biases at this level may reflect behavioural
472 tendencies of the over-represented species in the catch to form large aggregated popula-
473 tions in temperate regions that are readily accessible to fishing. Consumer preferences
474 may also be an important determinant of what taxonomic groups are more likely to
475 be caught. The over-representation of the Gadiformes and, to a lesser degree, the Clu-
476 peiformes, continues when caught and assessed taxa are compared (Figure 3, panels b
477 and c).

478 Historical economic importance as well as the geographic distribution of the taxa in
479 relation to mandated assessments may play important roles in determining what fished
480 taxa are assessed. Even in developed countries, however, not all stocks are assessed.
481 For example, in 2007, of the 528 fish and invertebrate stocks recognized by the Na-
482 tional Marine Fisheries Service (NMFS), only 179, or slightly over one-third, were fully
483 assessed (National Marine Fisheries Service, 2008). An assessment by the European
484 Environment Agency (EEA) in 2006 indicated that the percentage of commercial land-
485 ings obtained from assessed stocks ranged between 66-97 percent in northern European
486 waters and 30-77 percent in the Mediterranean (European Environment Agency, 2009).
487 The New Zealand Ministry of Fisheries reports the status of 117 stocks or sub-stocks
488 out of a total of 628 stocks managed under New Zealand’s Quota Management System
489 (New Zealand Ministry of Fisheries, 2009). In Australia, 98 federally managed stocks
490 have been assessed (Wilson *et al.*, 2009) out of an unknown total. The extent to which
491 stocks are assessed elsewhere in the world is currently unknown.

492 *Temporal bias*

493 Most of the assessments in the RAM Legacy database contain time series of 30 years
494 or less whereas industrial fishing began long before this. Dominant age-structured as-

495 assessment methodologies typically rely on catch-at-age data, which are often available
496 for considerably shorter periods of time than total catch unless significant reconstruc-
497 tion efforts are made. Such historical reconstructions of catch-at-age data are highly
498 uncertain and in many cases the “base case” models used for management are based
499 only on more reliable recent catch data. For assessments used in a tactical sense and
500 for short-term projection, e.g., to understand whether a particular quota level will re-
501 sult in an increase or decrease in stock size, using only reliable recent catch data may
502 be preferable. This is particularly true for backward projection methods (e.g., VPA),
503 which may converge on parameter estimates within the more reliable recent period and
504 potentially benefit little from reaching further back in time. Nevertheless, a focus on
505 only the recent history of a fishery can be seriously misleading for strategic decisions
506 about goals and BRPs. Put simply, if we don’t know what’s historically possible (in
507 terms of stock size), it’s hard to know where we should set our goals. This “shifting
508 baseline” problem has been widely recognized (Pauly, 1995; Sáenz-Arroyo *et al.*, 2005),
509 but is still apparent in the relatively short time series of most assessments.

510 *Future applications of the RAM Legacy database*

511 We anticipate that this new database will be of utility for fisheries scientists, ecolo-
512 gists, and marine conservation biologists interested in conducting comparative analyses
513 of global fisheries status, collapse and recovery patterns, fisheries productivity or ma-
514 rine population dynamics. In addition to the initial aim of providing reliable access to
515 time series information about stocks, we hope to also stimulate research in the relation-
516 ships of life-history characteristics and their relation to exploitation. The RAM Legacy
517 database contains the corresponding species codes to the Sea Around Us Project and
518 FishBase, thus facilitating researchers’ use of a global fisheries data “toolkit” to address
519 questions on the relationships between life history attributes and resulting population
520 dynamics in an exploited setting.

521 *Caveats and limitations*

522 Stock assessment outputs (e.g. biomass time series), which comprise the majority of
523 the new RAM Legacy database are model estimates, not raw data. The uncertainty as-
524 sociated with these estimates should be carried forth in subsequent analyses. Although
525 the database structure allows for inclusion of estimates of uncertainty (standard er-
526 rors, 95% credible/confidence intervals), because these estimates were typically missing
527 from assessments, either because they weren't produced by the assessment model (e.g.
528 non-bootstrapped VPA assessments) or the focus of the assessment document was on
529 central tendency (e.g. mean biomass) not the associated uncertainty, they have not
530 been included in this first version of the database. Note that this view of assessment
531 uncertainty is changing with the advent of MCMC approaches to Bayesian inference for
532 assessments, bootstrap methods, statistical catch-at-age models (ADMB Project, 2009)
533 and a general focus on uncertainty (Walters and Maguire, 1996). As with any analysis,
534 clearer inference on the strength of a signal is available when all uncertainty in the data
535 is carried forth. This represents a difficulty for synthetic analyses of fisheries data in
536 that in an ideal world one would access the raw data for each stock and carry forth
537 the uncertainty at all levels of the analysis. In the case of assessments, the raw data is
538 typically catch-at-age matrices and potentially survey indices. To understand the fleet
539 characteristics and survey stratification schema for each stock in a potentially global
540 meta-analysis would be extremely time consuming and error-prone. Instead, the expert
541 opinion of those researchers most familiar with the data, stock assessment authors, is
542 used, while recognizing that without accompanying uncertainty estimates the strength
543 of conclusions drawn may be weakened.

544 While the database provides detailed trends for individual stocks, it will never have
545 the geographic and taxonomic coverage provided by catch statistics. Assessment results
546 will also never replace the essential role played by fisheries-independent scientific surveys
547 in determining abundance, biomass and diversity trends in marine living resources.

548 BRPs derived from surplus production models are to be interpreted with great
549 care. For stocks where both were available we found that Schaefer-derived B_{msy} were

550 systematically higher than those obtained from assessments. This stems from the fact
551 that under the Schaefer surplus production model, MSY occurs at 50% of the carrying
552 capacity whereas in most age-based assessment models, yield is maximised at a lower
553 fraction of the carrying capacity.

554 The original database developed by Ransom A. Myers was used to address a vari-
555 ety of ecological questions derived from stock-recruit relationships. This was possible
556 because the VPA-type assessment models that comprised most of that database gen-
557 erated time series of stock and recruitment with relatively few a priori assumptions.
558 Forward projection methods generally specify the form of the stock-recruit relationship,
559 and in many cases even fix parameters (infinitely dense point prior) such as steepness.
560 Stock-recruitment “data” from such models, are clearly inappropriate for straightfor-
561 ward meta-analysis. In general, as more assessments incorporate some type of prior
562 information from other stocks or species (Hilborn and Liermann, 1998), there is less
563 stock-specific information available for future meta-analysis. One solution is for stock
564 assessments to report not only best estimates of parameters based on all available data,
565 but also stock-specific parameter estimates that do not incorporate prior information
566 from other stocks or species.

567 *Future development*

568 We anticipate that the RAM Legacy database will continue to grow with hith-
569 erto unentered stocks e.g. freshwater and anadromous populations, particularly the
570 Salmonidae that comprised 45% of the stocks in the original Myers Stock Recruit-
571 ment Database, and updated assessments for already included stocks. Future versions
572 of the database will also include timelines of management actions per stock, as well
573 as age-varying and length-varying data such as maturity ogives and age-disaggregated
574 natural mortality. Depending on availability, subsequent releases of the database could
575 also include estimates of assessment uncertainty. Future database products will in-
576 clude management-agency-level reports containing summaries of all stocks within their
577 remit. The development of a standard for assessment reporting at the management

578 agency level would greatly assist in the acquisition of new assessments, and hence to
579 ensure that the database remains current. For example, ICES assessments have a very
580 regular standard, including agreed-upon reference points and regular estimate report-
581 ing. This makes the process of data collation much more routine than unstandardized
582 documents where the recorder trawls through a report for the relevant information.
583 ICES also has a central database of assessments for stocks of the region. Certainly
584 different stocks and regions require different formats but basic output tables, consisting
585 of total and spawning biomass, recruitment, catch/landings, estimated fishing mortal-
586 ity over vulnerable age groups, associated measures of uncertainty, and commonly-used
587 reference points would streamline the process immensely. A process whereby the as-
588 sessment spreadsheets are filled out at each assessment meeting would facilitate the
589 process even further and be the least error prone method. In return, the assessment
590 scientists can access results for a global collation of assessments to further their own
591 research initiatives in population assessment and management. The ultimate goal is to
592 provide a comprehensive stock assessment database for researchers to use results from
593 multiple regions to assist in their own applied and fundamental research in population
594 ecology, fisheries science, and conservation biology.

595 **Availability of the database**

596 Contributions or corrections to the existing database, as well as requests to use the
597 database (subject to standard “Fair Use” policies), should be directed to the corre-
598 sponding author.

599 **Acknowledgments**

600 We sincerely thank all of the fisheries scientists whose assessments form the ba-
601 sis of this new global database. We are also grateful for the database contributions,
602 advice, and support of Trevor Branch, Jeremy Collie, Laurence Fauconnet, Mike Foga-
603 rty, Rainer Froese, Ray Hilborn, Jeff Hutchings, Simon Jennings, Heike Lotze, Pamela
604 Mace, Michael Melnychuk, Ana Parma, Renée Préfontaine, Kate Stanton, Reg Watson,
605 Boris Worm, Dirk Zeller, and the financial support of the National Science Foundation
606 through an NCEAS Working Group, the Natural Sciences and Engineering Research
607 Council (NSERC) of Canada, the Canadian Foundation for Innovation, the David H.
608 Smith Conservation Research Fellowship, the Schmidt Research Vessel Institute, and
609 the Census of Marine Life (CoML/FMAP).

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

<i>Country/Ocean</i>	<i>Management Body</i>	<i>Acronym</i>	<i>No. stocks</i>
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 Organi-	SPRFMO	1

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).

<i>Stock Rank</i>	<i>Stock Number</i>	<i>Species (Common name, Latin name) or higher taxonomic unit</i>	<i>LME</i>	<i>In Database?</i>	<i>Reason if not included</i>
1	1	Peruvian anchoveta, <i>Engraulis ringens</i>	Humboldt Current	x	3
2		Marine fishes not identified	South China Sea	x	1
3		Marine fishes not identified	Bay of Bengal	x	1
4	2	Alaska pollock, <i>Theragra chalcogramma</i>	Okhotsk Sea	✓	
5	3	<i>Ammodytes</i>	North Sea	✓	
6	4	Atlantic herring, <i>Clupea harengus</i>	Norwegian Sea	✓	

Continued on next page

<i>Stock Rank</i>	<i>Individual species rank</i>	<i>Species (Common name, Latin name) or higher taxonomic unit</i>	<i>LME</i>	<i>In Database?</i>	<i>Reason if not included</i>
7	5	Alaska pollock, <i>Theragra chalcogramma</i>	East Bering Sea	✓	
8	6	Capelin, <i>Mallotus villosus</i>	Iceland Shelf/Sea	✓	
9	7	European pilchard, <i>Sardina pilchardus</i>	Canary Current	✓	
10	8	Japanese anchovy, <i>Engraulis japonicus</i>	East China Sea	x	3
11	9	Inca scad, <i>Trachurus murphyi</i>	Humboldt Current	✓	1
12	10	Marine fishes not identified	East China Sea	x	
13		Gulf menhaden, <i>Brevoortia patronus</i>	Gulf of Mexico	✓	
14		Marine fishes not identified	Yellow Sea	x	1
15	11	Marine fishes not identified	Indonesian Sea	x	1
16		Alaska pollock, <i>Theragra chalcogramma</i>	Gulf of Alaska	✓	

Continued on next page

<i>Stock Rank</i>	<i>Individual species rank</i>	<i>Species (Common name, Latin name) or higher taxonomic unit</i>	<i>LME</i>	<i>In Database?</i>	<i>Reason if not included</i>
17	12	Argentinean short-finned squid, <i>Illex argentinus</i>	Patagonian Shelf	x	1
18	13	Argentine hake, <i>Merluccius hubbsi</i>	Patagonian Shelf	✓	
19	14	Japanese anchovy, <i>Engraulis japonicus</i>	South China Sea	x	1
20	15	Araucanian herring, <i>Strangomera bentincki</i>	Humboldt Current	x	?
21	16	Atlantic cod, <i>Gadus morhua</i>	Barents Sea	✓	
22	17	European sprat, <i>Sprattus sprattus</i>	Baltic Sea	✓	
23	18	Atlantic herring, <i>Clupea harengus</i>	North Sea	✓	
24	19	Alaska pollock, <i>Theragra chalcogramma</i>	Arctic Ocean	x	?
25		Marine fishes not identified	Gulf of Thailand	x	1

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<i>Stock Rank</i>	<i>Individual species rank</i>	<i>Species (Common name, Latin name) or higher taxonomic unit</i>	<i>LME</i>	<i>In Database?</i>	<i>Reason if not included</i>
26	20	Atlantic herring, <i>Clupea harengus</i>	Baltic Sea	✓	
27	21	Cape horse mackerel, <i>Trachurus capensis</i>	Benguela Current	✓	
28	22	Largehead hairtail, <i>Trichiurus lepturus</i>	East China Sea	x	?
29	23	Japanese anchovy, <i>Engraulis japonicus</i>	Yellow Sea	x	?
30	24	European anchovy, <i>Engraulis encrasicolus</i>	Black Sea	x	?
31	25	Chub mackerel, <i>Scomber japonicus</i>	East China Sea	x	?
32	26	Indian oil sardine, <i>Sardinella longiceps</i>	Arabian Sea	x	1
33		<i>Decapterus</i>	South China Sea	x	?
34		<i>Sciaenidae</i>	Arabian Sea	x	?

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<i>Stock Rank</i>	<i>Individual species rank</i>	<i>Species (Common name, Latin name) or higher taxonomic unit</i>	<i>LME</i>	<i>In Database?</i>	<i>Reason if not included</i>
35	27	Atlantic mackerel, <i>Scomber scombrus</i>	North Sea	✓	
36	28	Largehead hairtail, <i>Trichiurus lepturus</i>	Yellow Sea	x	?
37		<i>Merluccius</i>	Benguela Current	✓	
38		Marine fishes not identified	Kuroshio Current	x	?
39	29	Alaska pollock, <i>Theragra chalcogramma</i>	Sea of Japan	x	?
40	30	Round sardinella, <i>Sardinella aurita</i>	Canary Current	x	?

756 **Figures**

757 *Figure legends*

758 Figure 1. Global map of Large Marine Ecosystems (LMEs) and High Seas Areas (ovals)
759 showing the number of stock assessments present in the database for each area.

760

761 Figure 2. Taxonomic coverage of assessed marine species present in the RAM Legacy
762 database. The circle located near the middle of the circular dendrogram represents
763 kingdom Animalia and each subsequent branching represents a different taxonomic
764 group (Kingdom to Phylum to Class to Order to Family to Genus to Species). The
765 width of each line is proportional to the square root of the number of assessments in
766 the database. The outermost lines represent species and the number of lines is the
767 number of assessments for each species. The names of multi-assessment species are not
768 repeated on the outermost portion of the dendrogram but continue counter-clockwise
769 from the first entry. Note that branch lengths are chosen for graphical purposes and do
770 not convey phylogenetic distance.

771

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

778

779 Figure 4. Mean trophic level (obtained from FishBase) of the assessed species, grouped
780 by their B/B_{msy} and U/U_{msy} ratios.

781

782 Figure 5. Temporal coverage of (A) catch/landings, (B) spawning stock biomass and
783 (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 current biomass for 241 individual stocks. Exploitation is scaled relative to that which should allow maximum sustainable yield (U_{msy}); biomass is scaled relative to B_{msy} . Shades of grey indicate probability of occurrence as revealed by a kernel density smooth function. Solid circles indicate B_{msy} and U_{msy} that were obtained directly from assessments; open circles indicate that they were estimated from surplus production models.

Figure 7. Current exploitation rate versus biomass for individual stocks grouped by management unit. The panel labelled “Atlantic” comprises ICCAT and NAFO. Plot details as in Figure 6.

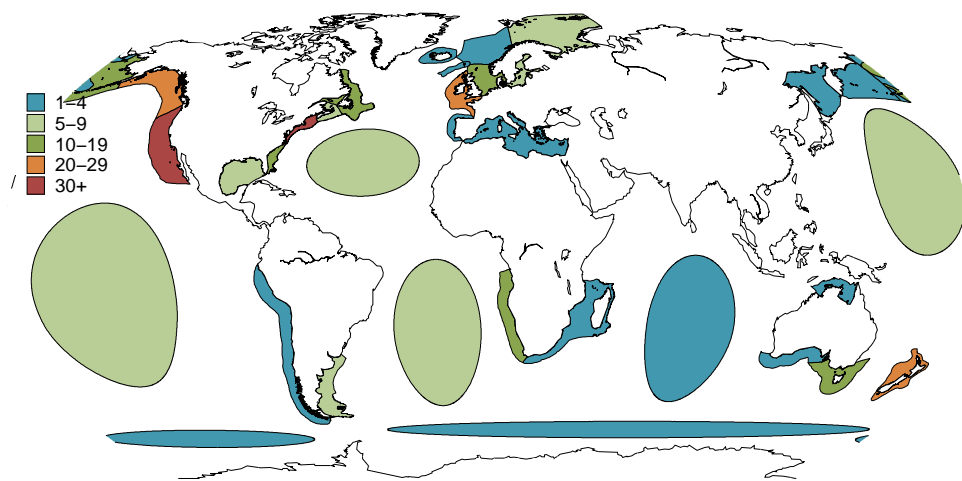
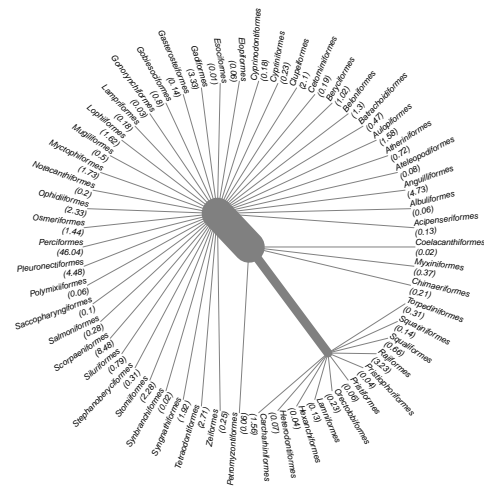
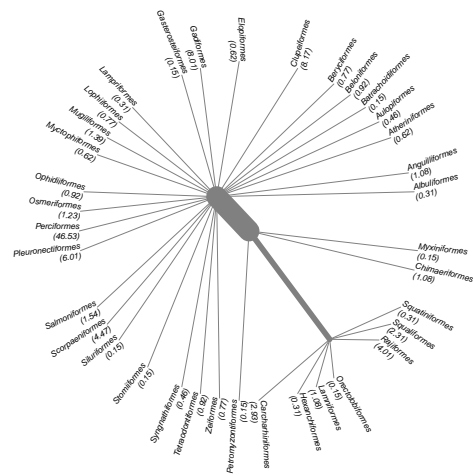


Figure 1:

FishBase



SAUP



RAM Legacy

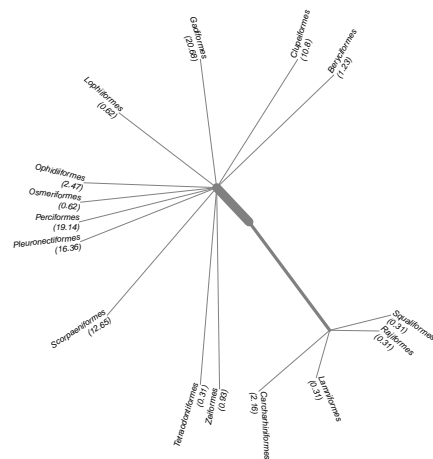


Figure 3:

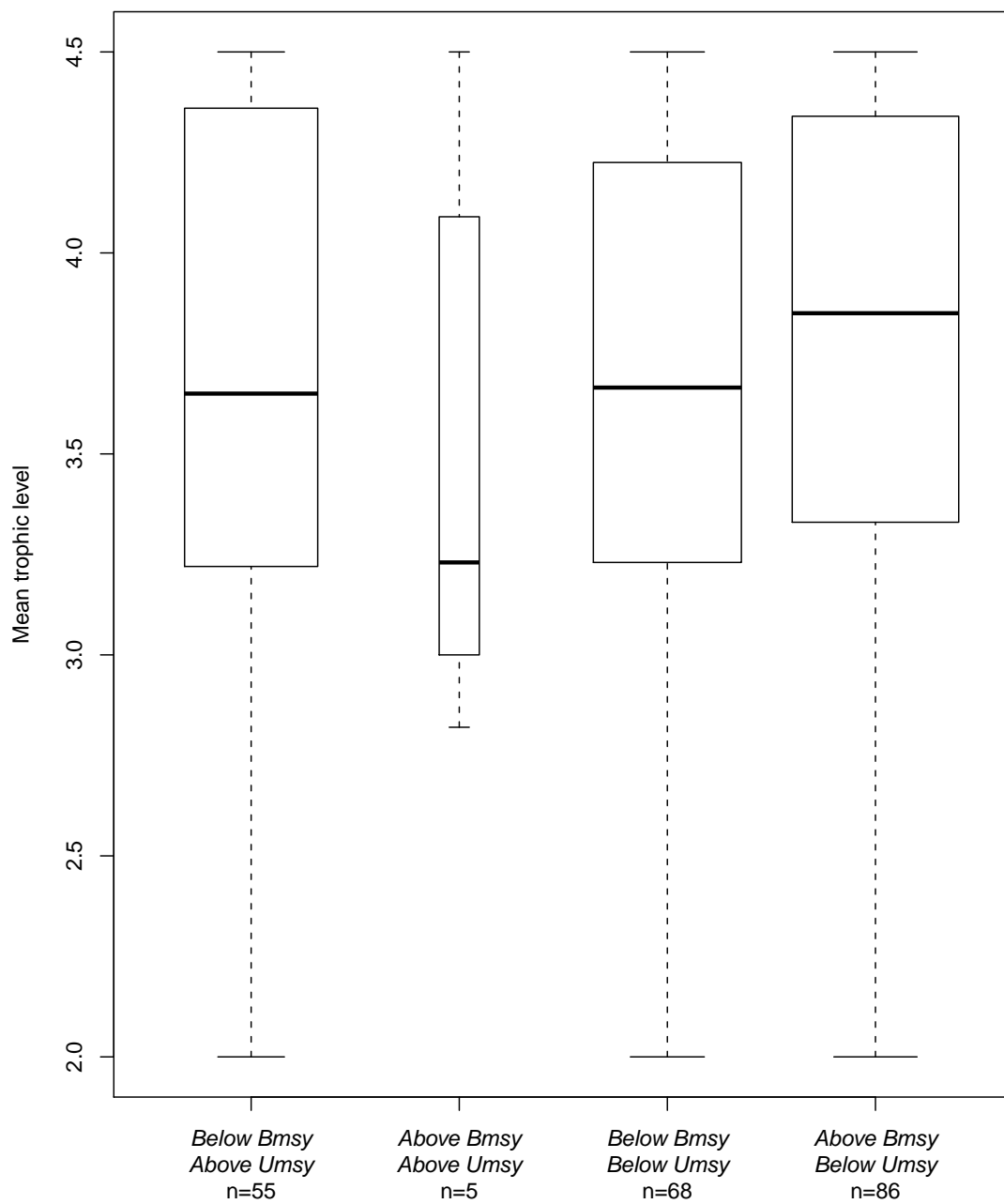


Figure 4:

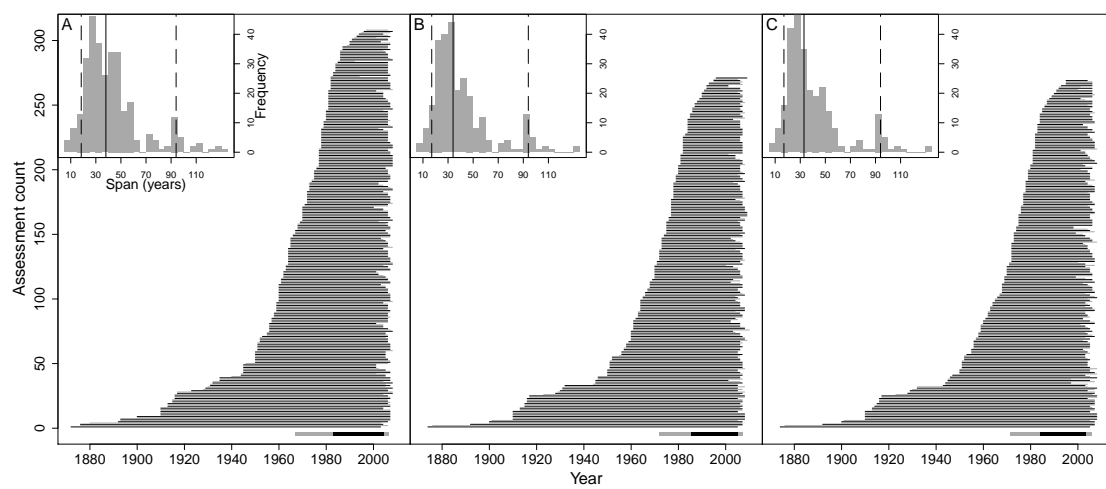


Figure 5:

all assessments (n=241)

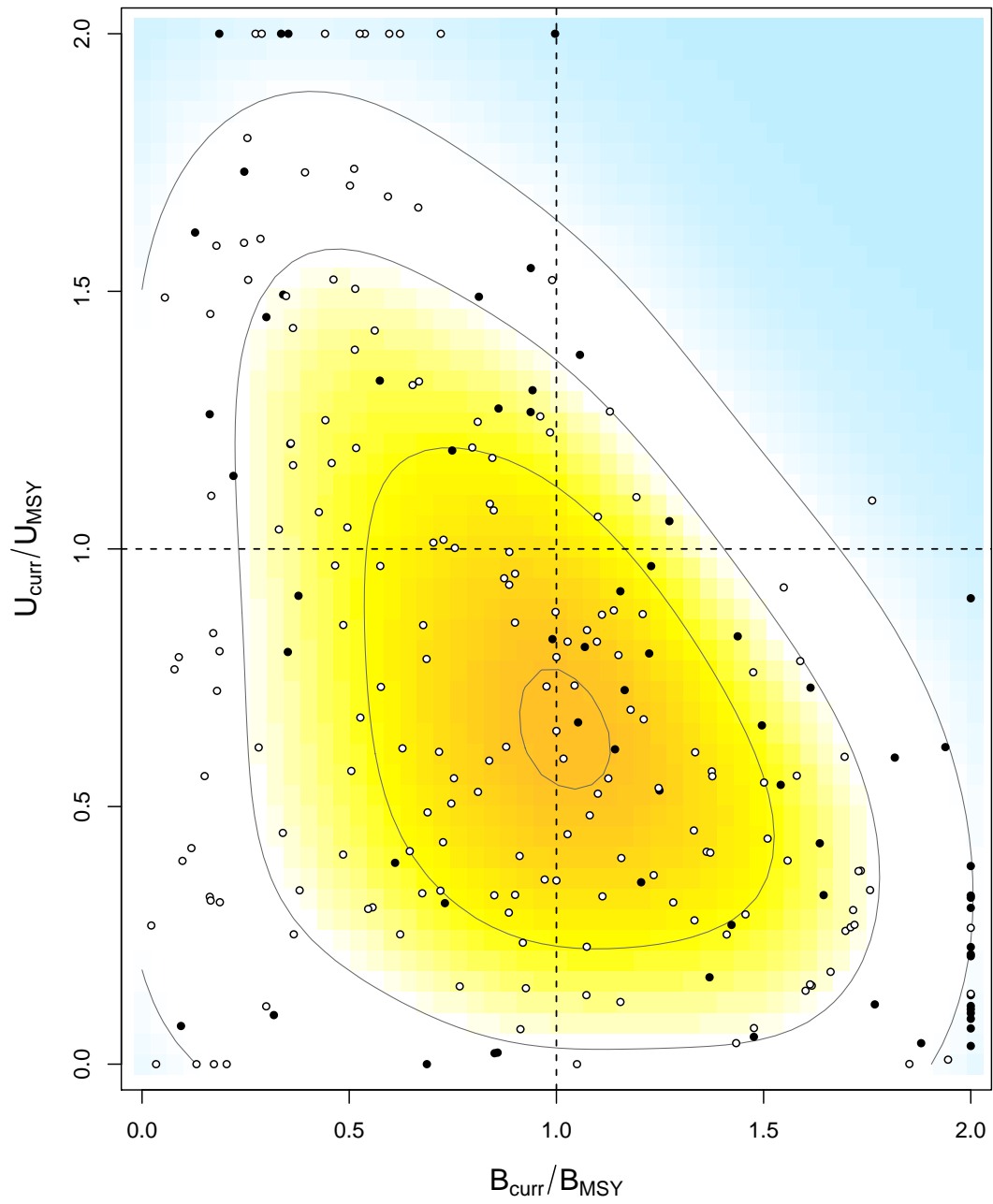


Figure 6:

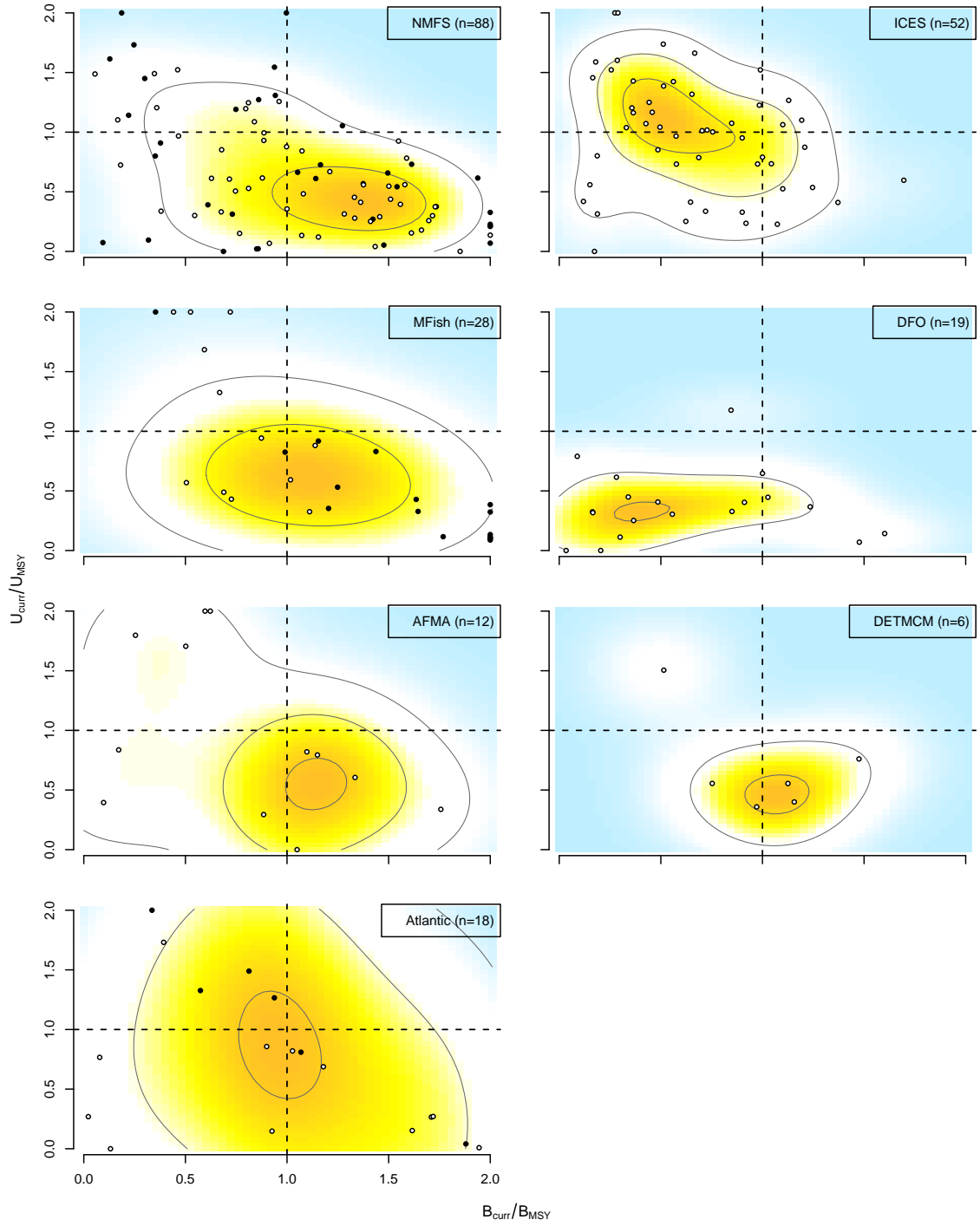


Figure 7: