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Global patterns of extinction risk in marine and non-marine systems

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Abstract:	Despite increasing concern over the effects of human activities on marine ecosystems [1, 2], extinction in the sea remains scarce: 19-24 out of a total of >850 recorded extinctions [3, 4] implies a 9-fold lower marine extinction rate compared to non-marine systems. The extent of threats faced by marine systems, and their resilience to them, receive considerable attention [2, 4-6], but the detectability of marine extinctions is less well understood. Before its extinction or threat status is recorded, a species must be both taxonomically described and then formally assessed; lower rates of either process for marine species could thus impact patterns of extinction risk, especially as species missing from taxonomic inventories may often be more vulnerable than described species [7-11]. We combine data on taxonomic description with conservation assessments from the IUCN to test these possibilities across almost all marine and non-marine eukaryotes. We find that the 9-fold lower rate of recorded extinctions and 4-fold lower rate of ongoing extinction risk across marine species can be explained in part by differences in the proportion of species assessed by the IUCN (3% cf. 4% of non-marine species). Further, once taxonomic knowledge and conservation assessments pass a threshold level, differences in extinction risk between marine and non-marine groups largely disappear. Indeed, across the best studied taxonomic groups there is no difference between marine and non-marine systems, with on average between 20 and 25% of species are threatened with extinction, regardless of realm.

Title: Global patterns of extinction risk in marine and non-marine systems

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Running Title: Global rates of extinction risk across realms

Summary:

Despite increasing concern over the effects of human activities on marine ecosystems [1, 2], extinction in the sea remains scarce: 19–24 out of a total of >850 recorded extinctions [3, 4] implies a 9-fold lower marine extinction rate compared to non-marine systems. The extent of threats faced by marine systems, and their resilience to them, receive considerable attention [2, 4-6], but the detectability of marine extinctions is less well understood. Before its extinction or threat status is recorded, a species must be both taxonomically described and then formally assessed; lower rates of either process for marine species could thus impact patterns of extinction risk, especially as species missing from taxonomic inventories may often be more vulnerable than described species [7-11]. We combine data on taxonomic description with conservation assessments from the IUCN to test these possibilities across almost all marine and non-marine eukaryotes. We find that the 9-fold lower rate of recorded extinctions and 4-fold lower rate of ongoing extinction

risk across marine species can be explained in part by differences in the proportion of species assessed by the IUCN (3% cf. 4% of non-marine species). Further, once taxonomic knowledge and conservation assessments pass a threshold level, differences in extinction risk between marine and non-marine groups largely disappear. Indeed, across the best studied taxonomic groups there is no difference between marine and non-marine systems, with on average between 20 and 25% of species are threatened with extinction, regardless of realm.

Highlights:

- The extinction risk of proportionally fewer marine than non-marine species is known
- Conservation assessments focus on taxonomically well-known groups in both realms
- In both realms, extinction risk increases with conservation assessment effort
- In well-known marine and non-marine taxa, between 20 and 25% of species are at risk of extinction

Results

Across all species, rates of extinction are higher in non-marine species

Rates of taxonomic description, IUCN assessment, extinction and extinction risk for 226,101 marine and 1,463,813 non-marine species are summarised in fig 1. Based on estimates of taxonomic completeness for the focal taxonomic groups [10, 12, 13] a similar proportion of all marine (27%) and non-marine (28%) species have been described. These estimates are highly uncertain, but the similarity between marine and non-marine groups agrees with previous analyses of smaller sets of species [13]. The IUCN lists 20 of described marine species as recently extinct (0.009%) and 1,206 (0.53%) as threatened with extinction. Rates of extinction (0.057%) and threat (1.37%) are respectively 6.42x and 2.60x higher per described non-marine species. This discrepancy is in part due to the fact that only 3.02% of described marine species have been IUCN-assessed, cf. 3.61% of described non-marine species. Extinction and threat rates per assessed species are 0.29% and 17.49% for marine species, respectively 5.4x and 2.2x lower than the rates for non-marine species (1.57% and 38.00%; fig 1).

Fewer marine species occur in well-described, well-assessed taxonomic groups

IUCN assessments are disproportionately focused on species within the 19 marine and 10 non-marine groups that we define as taxonomically well-described. 63.8% of assessed marine and 87.9% of assessed non-marine species occur in these groups (table 1, fig 2), which also include most recorded extinctions (70.0% of marine and 89.9% of non-marine) and current threatened species (54.3% of marine and 87.0%

64 of non-marine). Importantly, more non-marine than marine species occur within
65 well-described groups, in absolute numbers (406,778 in 10 non-marine groups cf.
66 38,011 in 19 marine groups; table 1), proportions of described species (27.8% non-
67 marine cf. 16.8% marine), and proportions of predicted total species numbers
68 (10.0% non-marine cf. 5.2% marine).
69 We define 11 marine and 8 non-marine groups as well-assessed by the IUCN
70 (of which 6 and 7 respectively are also well-described; table 1). These contain
71 42.7% of all described and 98.8% of all assessed marine species, and 25.5% of
72 described and 96.9% of assessed non-marine species. These well-assessed groups
73 contain substantially more described non-marine (372,724) than marine (96,651)
74 species.
75
76 *Apparent threat increases with conservation assessment in both realms*
77 Across well-assessed groups, the proportion of *described* species listed as
78 threatened or extinct increases with the proportion IUCN-assessed in both marine
79 and non-marine taxa (fig 3A). The relationship differs across realms (binomial GLM,
80 significant interaction between P(assessed) and realm, z = -18.77, $P < 0.0001$), but
81 differences between realms – particularly at higher values of P(assessed) – are
82 relatively minor compared to differences within realms. Precise predictions are
83 unwise as our model does not attempt to explain differences in 'true' threat rates (at
84 100% assessment) between groups; however, threatened species accumulate faster
85 as more species are assessed in the marine realm, such that the lines for the two

86 realms cross when *c.* 80% of species within a group are IUCN-assessed (fig 3A). At
87 this level of assessment, 15-25% of described species are predicted to be threatened
88 or extinct regardless of environment.
89 The proportion of *assessed* species that are threatened or extinct
90 (P(threatened, extinct | assessed)) in these groups (fig 3B) is also related to the
91 proportion assessed, with clear differences between realms (significant interaction
92 between P(assessed) and realm, $z = -16.7$, $P < 0.0001$), consistent with assessment
93 efforts focusing on at-risk species first in non-marine but not in marine groups.
94 Considering only those groups in which P(assessed) is high enough for this
95 discrepency to lessen (> 1/3 of described species assessed), the proportion of
96 assessed species that are threatened or extinct is similar (and similarly variable) in
97 marine (mean ± sd 0.23±0.106, n = 5) and non-marine (0.26±0.111, n = 6) groups.
98 Regardless of realm, in groups for which estimates of extinction rates are likely to be
99 most robust, on average 20-25% of IUCN-assessed species are extinct or at risk of
100 extinction.
101 ***Discussion***
102 The oceans have a habitable volume 600 times larger than the terrestrial biosphere
103 [14]. This vast realm is mostly inaccessible to us which leads to the assumption that
104 human-driven marine extinctions are unlikely. Superficially, IUCN data bears this
105 out: according to our criteria, only 20 marine extinctions have been recorded across
106 just six of the 88 marine taxonomic groups we consider (6 seabirds, 5 fish, 4
107 gastropod molluscs, 3 marine mammals, 1 nemertean worm, and 1 red alga), within
108 the range of previous estimates [4, 5]. Similar discrepencies occur within groups

occurring in both realms: extinction of 1.8% of non-marine molluscs is a rate >250x that observed in marine molluscs (0.007%) [15], and although similar numbers of fish species occur in marine and freshwater habitats [16], >10x more freshwater (N = 66) than marine species (N = 5) have been recorded as extinct.

However, anthropogenic activities are pervasive and increasing throughout the oceans [2, 17-20], and so determining whether marine extinctions are truly unlikely or simply hard to detect is important. We show that differences between realms in observed rates of extinction and extinction risk are at least partially explained by differences in the degree to which species have been described and assessed. In particular, extinction risk is similar in marine and non-marine systems in the best known taxonomic groups, i.e. those that have been both well-described taxonomically and well-assessed by the IUCN (fig 3). This is supported by previous work on individual taxonomic groups, which reveal high levels of threat within certain marine taxa: 30% of seabirds [21], 33% of reef building corals [22], and at least 25% of sharks and rays [23] are at an elevated risk of extinction, rates comparable with non-marine groups widely considered to be highly threatened (e.g. 33% of amphibians [24]).

These results suggest the arguments that marine species possess 'extinction resistance' traits such as high fecundity, large ranges and high dispersal ability [25-28] are overly simplistic, and neglect much variation within each realm [29]. For instance, although some marine species have large ranges, most do not: just as on land, rarity is the norm in marine systems [11, 29, 30]. Equally, supposed 'extinction resistance' traits may not actually confer low risk of extinction: species with high

dispersal potential can exhibit genetic differentiation over small scales [31, 32] or be tied to specific sites (and thus potentially vulnerable) for large parts of their lives [33]; and high fecundity does not predict how well marine fish populations recover following overexploitation [34]. There is little empirical support for *a priori* expectations of high levels of intrinsic extinction resistance in marine species.

Marine groups that have been well-assessed by the IUCN are, however, primarily coastal, dependent on terrestrial habitats for crucial parts of their lifespans, or air-breathing, and it could be argued that these groups have more regular contact with humans than is typical of marine taxa, although it is not obvious that this should lead to a higher risk of extinction compared with other, less conspicuous taxa occurring in similar environments, for example *Conus* gastropods [35]. Such groups are also typically less speciose in the sea than on land, with 15x fewer seabird species and 40x fewer marine mammal species than non-marine members of the same groups. This paucity of marine species in charismatic groups may contribute to the overall lack of marine assessed species. In contrast, we know next to nothing about extinction risk in many marine taxa: 73% of the 88 groups we consider here (table S1), constituting 31% of all known marine species, have had no assessments at all. Finally, considerable controversy exists over applying IUCN criteria to some marine taxa, especially commercially fished species [36, 37], suggesting that extinction risk may be underestimated in some groups.

Two other factors may also lead to underestimation of marine extinction risk. First, rates of 'Data Deficient' (DD) IUCN classifications in marine taxa (28.6%; 2,730 of 9,554 assessed species) are double those in non-marine taxa (14.7%; 9,365 of

63,909 species). DD species often have ecological and life history traits which lead to a high likelihood of being threatened [11, 23, 38-40] suggesting that improved knowledge of marine taxa is likely to increase the number of documented extinct and threatened species. Such efforts are challenging because species poorly known in one respect (e.g. their geographic distribution) also tend to be poorly known in others (e.g. their biological traits [41]). Second, fig 3B suggests that non-marine assessment efforts may target the most vulnerable members of a taxonomic group first, whereas no such trend is discernable in the marine realm. It makes sense to target first taxa likely to be at risk, but this further complicates comparisons across realms.

We find little evidence for differences in global extinction risk between marine and non-marine taxa, with approximately 20-25% of species within a group at risk of extinction in both realms (fig 3B). This comparison is based on the assumption that a robust estimate of extinction risk within a taxonomic group requires both a high level of taxonomic description (as the species described first within any group are typically those which are most common and least likely to be threatened) [10], and considerable conservation assessment effort within those groups. Further effort is needed to test whether these results are representative of all taxa, and thus whether 20-25% species are indeed threatened with extinction across realms, regardless of estimates of total species number. The paucity of recorded marine extinctions does however suggest that the threat to marine species may not yet be sufficiently great to force many to extinction, in part because the geographic scale of human activities in the seas has increased markedly only in the

178 last century [19]. This buys time to implement conservation efforts before species
179 are lost [42], yet the loss of marine populations is already common [4], and so the
180 lack of recorded global extinctions is not cause for complacency. Rather it should
181 spur us on to trying to achieve a better understanding of the species which inhabit
182 our oceans and the threats that they face, taking action to increase rates of
183 taxonomic description and assessment of extinction risk [42] in order to prevent a
184 biodiversity crisis in the oceans as severe as that on land.
185
186 ***Experimental Protocols***
187 ***Species lists and taxonomic description rates***
188 We assembled lists of species occurring within taxonomic groups for which
189 estimates of both described and undescribed species numbers are available. We
190 grouped species into 88 major eukaryotic marine taxonomic groups listed in [12]
191 (see *Supplemental Experimental Protocols* for details), which together include
192 226,101 valid marine species names (>99% of all valid marine species in the World
193 Register of Marine Species WoRMS; [44]). We calculated for each group the
194 proportion of species described, using the number of known species and the
195 midpoint of the minimum and maximum number of total species [43], which results
196 in an estimated total 828,756 marine species (table S1). There is uncertainty around
197 estimates of total species across all groups (698,918—958,593) and within each
198 taxon, but the groups that are well-described on which we focus most attention
199 typically have lower ranges of estimated total species (see *Supplemental*
200 *Experimental Protocols* and figure S1). Non-marine data are based on estimates of

the completeness of description for 19 groups of various ranks [10,45] (see *Supplementary Experimental Protocols*). Our final list includes 1,463,813 non-marine described species and 5,192,742 estimated total species (table S1). There is no comprehensive list of all valid non-marine described species, but some estimates are as low as ~1M species [46] so we are confident that our list constitutes a large fraction of all described non-marine eukaryotes. In both realms, we define 'well-described' groups as those in which at least 2/3 of the estimated total number of species have already been described (table 1).

Estimates of extinctions and extinction risk

We extracted the full list of 73,686 species assessed by the IUCN [3](search URL http://www.iucnredlist.org/search/link/53a02f68-f6a97179, accessed June 2014) and matched it to the full list of 431,871 names (including synonyms and unaccepted names) occurring in WoRMS [44] at the 'species' rank. Further details including definitions of marine species and procedures for dealing with taxonomic disagreements between sources are given in Appendix S1. 97% of species on the IUCN list were assigned to one of the taxonomic groups listed in table S1, totalling 9,554 marine species and 61,664 non-marine species.

Species classified as 'Data Deficient' (DD) by the IUCN have undergone a formal assessment process; however, we consider such species to be too poorly known to contribute usefully to our analysis of extinction risk, and so hereafter we use 'assessed' to refer only to the 6,824 marine and 54,544 terrestrial species in our dataset that have an IUCN category other than DD. The rate of DD assessments in marine taxa (28.5%; 2,752 of 9,659 species) is double that in non-marine taxa

224 (14.7%; 9,365 of 63,909 species), which has important implications for extinction
225 risk assesments (see Discussion).

226 ***Distribution of extinct and threatened species across taxonomic groups***

227 We summarise the number of extinct and threatened species in marine and non-
228 marine environments as proportions of all described and all IUCN-assessed species,
229 defining extinct species as all those classed as EX (extinct) or EW (extinct in the
230 wild) and threatened species as those falling into any of CR, EN or VU (critically
231 endangered, endangered, vulnerable). All other (non-DD) assessed species are not
232 considered to be at risk of extinction. We estimate the extent to which IUCN
233 assessments are concentrated in taxonomically well-described groups, and consider
234 how the relative richness of these taxonomically well-known groups differs between
235 realms.

236 ***Cross-realm analyses of 'well-assessed' groups***

237 We define 'well-assessed' groups as those in which at least 1/3 described species
238 have been assessed by the IUCN, or in which at least 90 species have been assessed
239 and where this figure represents ≥1% described species in the group. These criteria
240 rank groups such as Tracheophyta (non-marine, 17,568 of 281,621 species
241 assessed) and Gastropoda (marine, 650 of 32,000 species assessed) as well-assessed
242 but not groups such as Merostomata in which one of only 4 described species has
243 been assessed. Across these well-assessed groups, we test whether the relationship
244 between the proportion of threatened or extinct species P(threatened or extinct)
245 and the proportion of assessed species P(assessed) differs between the marine and
246 non-marine realms. We fit a binomial GLM of P(threatened or extinct) as a function

of P(assessed), realm (Marine or Non-marine), and their interaction. Finally, we test across well-assessed and well-described groups for a difference between realms in the proportion of assessed species that are threatened or extinct – that is, threat and extinction rates per assessed species, P(threatened, extinct | assessed) – and whether this varies across groups differeing in their levels of conservation assessment. We,fit a binomial GLM of P(threatened, extinct | assessed) as a function of P(assessed), realm, and their interaction. Both models are designed to test for general differences in extinction risk between marine and non-marine groups in which taxonomic and assessment effort are similar. All data manipulation and statistical analyses were performed in R 3.0.2 [43], and data and code are available on figshare (data: dx.doi.org/10.6084/m9.figshare.1258968, code: dx.doi.org/10.6084/m9.figshare.1258984).

Author Contributions

TJW and BLM designed the study and created the dataset, TJW analysed the data and created the figures, TJW and BLM wrote the manuscript.

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272
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Table 1. Numbers of total, described, and IUCN-assessed species in well-described (italics) and well-assessed (bold) groups of marine (Realm M) and non-marine (N) species. Total is the midpoint of estimates of total species richness for each group; Known is the total number of described species, Assessed is the number assessed by the IUCN (not including Data Deficient species), Threatened and Extinct are those assigned to the relevant IUCN categories. $P_{Threat \mid Assessed}$ is the proportion of Assessed species listed as either Threatened or Extinct. Groups are sorted within realm in descending order of the proportion of Total species that are Known. Groups illustrated in fig 3B are identified by the first three letters of their name, shown underlined here. Figures for all taxa, including poorly described groups, are available in Table S1.

			Number of Species					
Realm	Taxon	Rank	Total	Known	Assessed	Threatened	Extinct	$P_{Threat \mid Assessed}$
M	*Branchiopoda*	*class*	*90*	*90*	*1*	*0*	*0*	*0*
M	*Phoronida*	*phylum*	*18*	*18*	*0*			
M	***Mangroves*** [a]	***other***	***78***	***75***	***57***	***11***	***0***	***0.19***
M	***Mammalia***	***class***	***140***	***135***	***88***	***34***	***3***	***0.42***
M	*Hexapoda*	*other*	*2147*	*2037*	*1*	*1*	*0*	*1*
M	***Seagrasses*** [b]	***other***	***73***	***68***	***54***	***9***	***0***	***0.17***
M	*Hemichordata*	*phylum*	*128*	*118*	*0*			
M	***Aves***	***class***	***721***	***641***	***613***	***123***	***6***	***0.21***
M	*Polyplacophora*	*class*	*1055*	*930*	*0*			
M	*Crinoidea*	*class*	*723*	*623*	*0*			
M	*Thaliacea*	*class*	*92*	*79*	*0*			
M	*Myzozoa*	*phylum*	*3261*	*2686*	*0*			
M	***Reptilia***	***class***	***135***	***110***	***62***	***11***	***0***	***0.18***
M	*Echiura*	*phylum*	*218*	*175*	*0*			
M	*Foraminifera*	*phylum*	*7500*	*6000*	*0*			
M	*Merostomata*	*class*	*5*	*4*	*1*	*0*	*0*	*0*
M	*Asteroidea*	*class*	*2434*	*1922*	*0*			
M	***Pisces***	***other***	***21733***	***16733***	***3476***	***459***	***5***	***0.13***
M	*Ophiuroidea*	*class*	*2769*	*2064*	*0*			
M	**Anthozoa**	**class**	**8318**	**5230**	**678**	**224**	**0**	**0.33**
M	**Cephalopoda**	**class**	**1411**	**761**	**163**	**0**		
M	**Holothuroidea**	**class**	**3683**	**1683**	**95**	**11**	**0**	**0.12**
M	**Gastropoda**	**class**	**127000**	**32000**	**640**	**58**	**4**	**0.10**
M	**Malacostraca**	**class**	**204234**	**29748**	**816**	**215**		

N	***Aves*** [a]	***class***	***9279***	***9349***	***9380***	***1177***	***128***	***0.26***
N	***Mammalia***	***class***	***5360***	***5352***	***4625***	***1160***	***76***	***0.14***
N	*Mantodea*	*suborder*	*840*	*792*	*3*	*1*	*0*	*0.33*
N	*Orthoptera*	*order*	*26700*	*23541*	*28*	*21*	*1*	*0.79*
N	***Reptilia***	***class***	***9865***	***8624***	***3418***	***891***	***22***	***0.27***
N	***Odonata***	***order***	***6200***	***5416***	***1966***	***265***	***1***	***0.14***
N	***Pisces***	***other***	***18267***	***14536***	***5165***	***1697***	***66***	***0.34***
N	***Tracheophyta***	***division***	***368050***	***281621***	***17568***	***10381***	***124***	***0.60***
N	***Mollusca***	***phylum***	***54003***	***41311***	***4320***	***1863***	***320***	***0.51***
N	*Bryophyta*	*division*	*22750*	*16236*	*41*	*35*	*2*	*0.90*
N	**Amphibia**	**class**	**15000**	**6515**	**4794**	**1961**	**36**	**0.42**

[a] The number of described non-marine bird species is higher than the estimated total number of species because of variation in estimated species numbers between sources. Likewise, the number of assessed bird species exceeds the number of described species, likely due to synonymy within the IUCN database. We therefore assume that all non-marine bird species are known, and that all have been assessed by the IUCN. Minor variations around this figure will not affect our conclusions.

Figure Legends

Figure 1. Differences in numbers of total species, described species, IUCN assessed species, and threatened and extinct species, between marine and non-marine taxa. This figure is based on the >99% of described marine species and the large fraction of described non-marine species present in the 88 marine and 19 non-marine groups included in our dataset. The area of each box is proportional to the number of species it represents. Numbers along the horizontal arrows give differences (Δ) between realms as non-marine numbers (N) and proportions (P) as a multiple of the marine figure. For instance, the number of described species in the non-marine realm that have been IUCN-assessed is around 8 times higher than the in the marine realm ($\Delta N_{Assessed}$ x7.8), but the difference between realms in the proportion of described species that have been assessed is rather smaller (the difference in proportions assessed given described, $\Delta P_{Ass\ |\ Desc}$ x1.20). Vertical arrows give the number of species within a realm as a proportion of the numbers in the level immediately above it (e.g. x0.030 indicates that around 3% of described marine species have been assessed by the IUCN)..

Figure 2. Conservation assessment has been focused on well-known groups in both marine and non-marine realms. Here, the proportion of described species within each of the 88 marine and 19 non-marine groups included in our dataset which have been assessed by the IUCN is plotted as a function of the estimated level of taxonomic knowledge for each group (number of described species over estimated total species richness). Marine groups are shown in blue and non-marine

groups in green, and the size of each point is proportional to the number of described species in each group. Solid symbols represent those groups that we consider either taxonomically well-described (the proportion of known species exceeds 2/3, the vertical dashed line) or which have been well-assessed by the IUCN (the proportion of assessed species exceeds 1/3, the horizontal dashed line, OR the *number* of assessed species exceeds 90 and this constitutes ≥1% of species in the group). In general, the conservation status of large proportions of described species is known only for those groups in which taxonomic knowledge is high (i.e. most species have already been described). Amphibians (non-marine) are the clear outlier, with around 75% of known species having been assessed, despite estimates that only around 40% of all species have yet been described – a testament to their high conservation priority.

Figure 3. Conservation concern varies with conservation assessment effort in both marine and non-marine taxa. A Across only those groups that have been well-assessed by the IUCN, the proportion of species that are either extinct or threatened with extinction is higher in groups with higher proportions of assessed species. The lines show the fit of a binomial GLM of the proportion of threatened or extinct species within a group, P(Threat, Extinct) as a function of the proportion IUCN-assessed, P(Assessed), realm, and their interaction. In both realms, total threat rates for a group are expected to be around 20% of described species once around 80% of described species have been assessed. **B** The proportion of IUCN *assessed* species only that are threatened or extinct (P(Threat, Extinct | Assessed)) also varies

459 with the proportion of species within a group that have been assessed (P(Assessed);
460 solid lines, binomial GLM of P(Threat, Extinct | Assessed) on P(Assessed), realm, and
461 their interaction). At low values of P(Assessed), non-marine groups (green symbols)
462 tend to have a higher apparent threat rate than marine groups (blue symbols).
463 However, once P(Assessed) exceeds 1/3, this difference between the realms
464 disappears, with between 20 and 25% of assessed species in a group likely to be
465 threatened or extinct regardless of realm. Labels identify taxonomic groups by the
466 first three letters of their names, underlined in table 1.
467
468

Figure 1

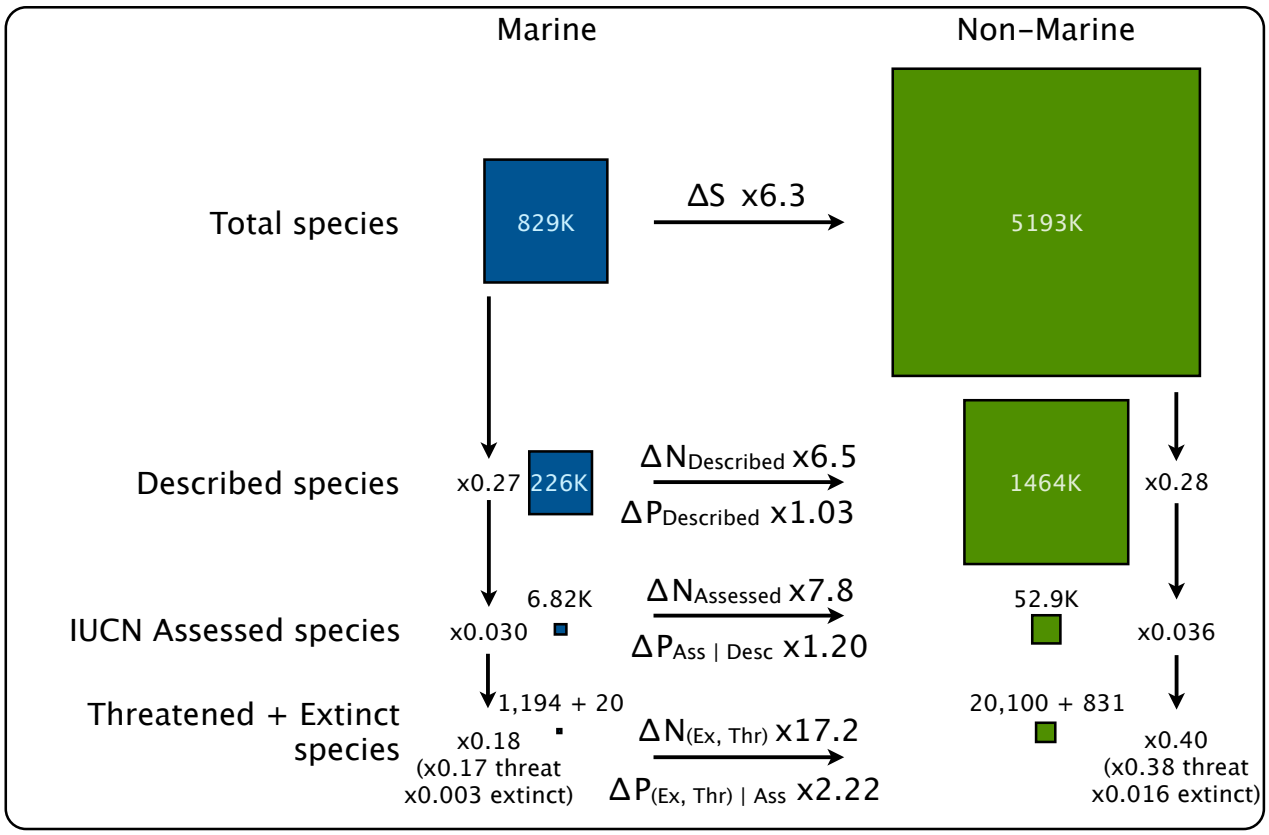

Marine
Non-Marine
Total species
829K
ΔS x6.3
5193K
Described species
x0.27
226K
ΔNDescribed x6.5
ΔPDescribed x1.03
1464K
x0.28
IUCN Assessed species
6.82K
x0.030
ΔNAssessed x7.8
ΔPAss | Desc x1.20
52.9K
x0.036
Threatened + Extinct species
1,194 + 20
x0.18
(x0.17 threat
x0.003 extinct)
ΔN(Ex, Thr) x17.2
ΔP(Ex, Thr) | Ass x2.22
20,100 + 831
x0.40
(x0.38 threat
x0.016 extinct)

Figure 2

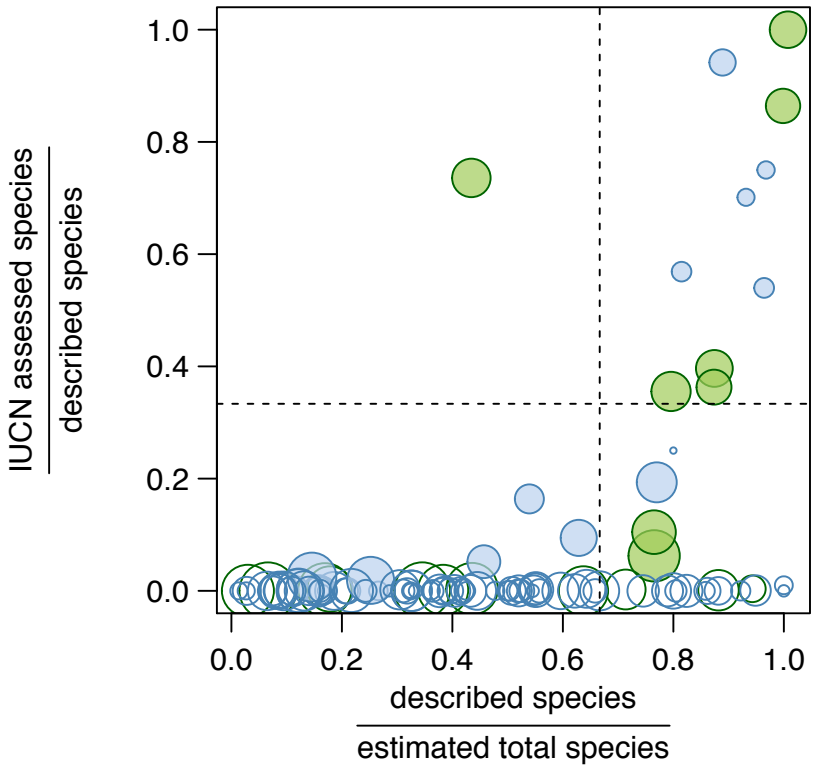
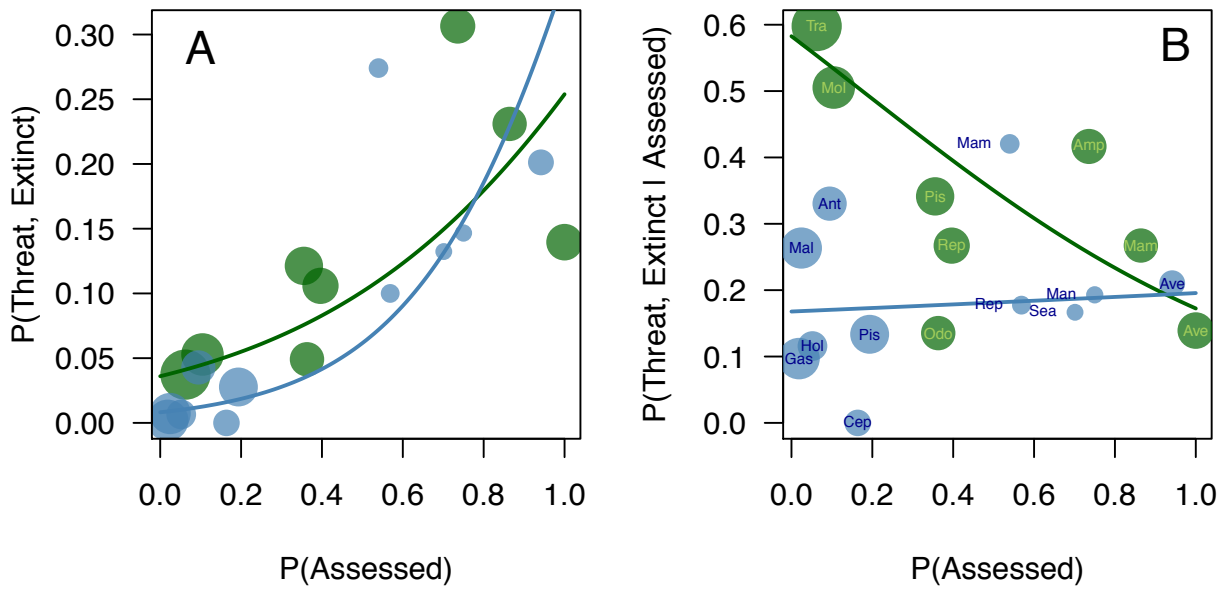

1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
IUCN assessed species
described species
described species
estimated total species

Figure 3


A
P(Threat, Extinct)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.0
0.2
0.4
0.6
0.8
1.0
P(Assessed)
B
P(Threat, Extinct | Assessed)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Tra
Mol
Mam
Amp
Pis
Ant
Mal
Rep
Mam
Ave
Man
Rep
Sea
Pis
Odo
Hol
Gas
Ave
Cep
0.0
0.2
0.4
0.6
0.8
1.0
P(Assessed)

Webb & Mindel, Global Rates of Extinction Risk Across Realms

Inventory of Supplemental Materials

Supplemental Data

Table S1, related to Table 1 included as CSV file, Webb_Mindel_tableS1.csv; table of metadata included in main Supplementary Materials file.

Figure S1, related to Figure 2

Supplemental Experimental Procedures

Supplemental References

Supplemental Data

Table S1, related to Table 1. Rates of taxonomic description, IUCN assessment, threat and extinction for all 88 marine and 19 non-marine taxonomic groups used in our analyses. For ease of re-use, we include this table as a separate spreadsheet, with each variable (i.e. each column in table S1) described below. This data table is also available via figshare (figshare.com/s/3fdb585e7ba911e493f606ec4bbcf141). Missing values are coded as NA.

Variable	Definition
realm	M for marine, N for non-marine groups
taxon	Taxonomic group
rank	Taxonomic rank
total.sp	Total estimated species richness
min.total	Minimum estimated total species richness
max.total	Maximum estimated total species richness
described.sp	Number of taxonomically described species
WoRMS2014.sp	Number of valid described species in WoRMS 2014 (marine groups only)
min.described	Minimum number of described species (non-marine groups only)
max.described	Maximum number of described species (non-marine groups only)
p.known	Proportion of total species so far described (described.sp / total.sp)
min.pknown	Minimum value for p.known (described.sp / max.total for marine groups, min.described / max.total for non-marine groups)
max.pknown	Maximum value for p.known (described.sp / min.total for marine groups, max.described / min.total for non-marine groups)
description.rate	Taxonomic description status: Lo, Med and Hi indicate p.known <1/3, 1/3 ≤ p.known < 2/3, and p.known > 2/3 respectively
assessed.sp	Total number of species assessed by the IUCN
dd.sp	Number of species assessed as Data Deficient (DD)
assessed.sp.nodd	Number of species assessed and *not* DD
assessment.rate	Level of IUCN assessment, Hi = assessed.sp.nodd > 2/3 * described.sp[a] *or* assessed.sp > 90 *and* 90 > 0.01 * described sp[a]; Lo = all other groups
threatened.sp	Number of threatened species (IUCN categories CR, EN, VU)
extinct.sp	Number of extinct species (IUCN categories EX, EW)
threatened.extinct.sp	Number of threatened or extinct species, threatened.sp + extinct.sp
non.threatened.sp	Number of assessed, non-threatened species (assessed.sp.nodd – threatened.extinct.sp)
p.assessed	Proportion of described species assessed by the IUCN and not DD, assessed.sp.nodd / described.sp[a]
p.threatened	Proportion of described species listed as threatened, threatened.sp / described.sp[a]
p.extinct	Proportion of described species listed as extinct, extinct.sp / described.sp[a]
p.threatened.assessed	Proportion of IUCN assessed, non-DD species listed as threatened *or* extinct, threatened.extinct.sp / assessed.sp.nodd

[a]For marine groups, we used WoRMS2014.sp as our measure of number of described species for all calculations of proportions of IUCN assessed, threatened, or extinct species.

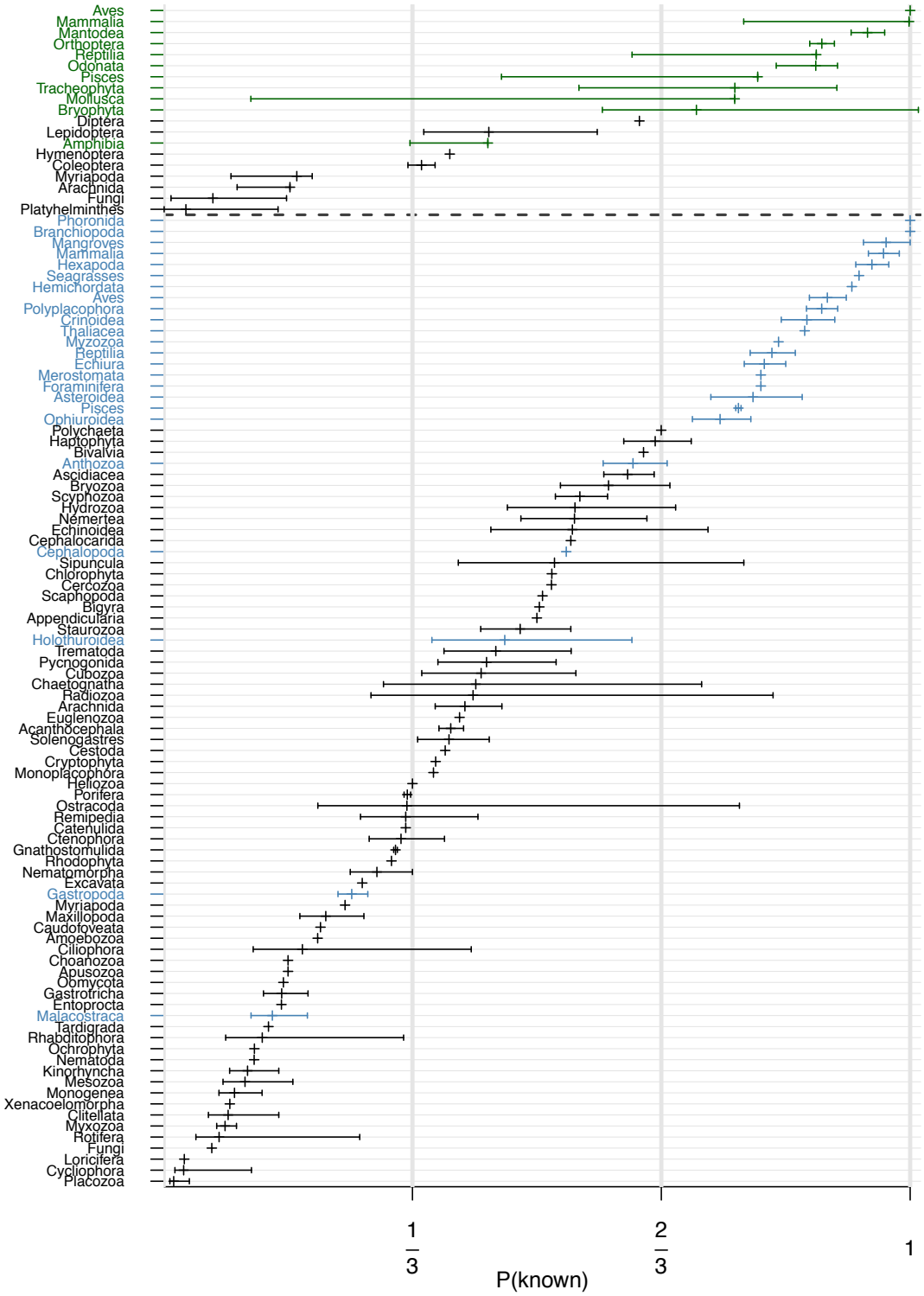


Figure S1, related to Figure 2 (see over for figure legend).

Figure S1, related to Figure 2. The range in estimated number of total species in each taxonomic group we consider that is currently described, using figures from [S1-S3]. Each point represents the midpoint of the proportion of species known for a given group, and horizontal bars represent the range in this proportion obtained by taking the minimum and maximum estimates of total species richness given in [S1-S3]. Marine groups are below the horizontal dashed line, and non-marine groups are above it. Groups shown in blue (marine) or green (non-marine) are those which we consider taxonomically well-described (P(known)≥2/3) and/or well assessed by the IUCN. Uncertainty in the numbers of total and described species in some groups occasionally lead to upper bounds >1.

Supplemental Experimental Procedures

Taxonomic data processing

For marine taxa, we amalgamate species into pragmatic taxonomic groupings based on Table 2 in [S1]. This results in 38 phyla, 44 classes, and 9 other well-defined groups (e.g. superclass Pisces, subphylum Hexapoda). Our list of mangrove species is from [S4] and http://www.vliz.be/vmdcdata/mangroves/ (accessed June 2014). Seagrasses include all marine species in Order Alismateles. We exclude three groups (phylum Brachiopoda, subphylum Cephalochordata, and class Priapulida) for which [S1] gives no estimates of unknown species, leaving us with 88 marine groups (table S1). Our estimates of total species richness for marine groups is based on the midpoint of the minimum and maximum number of unknown species given in [S1]. This ignores considerable uncertainty in total species richness estimates for some groups (fig S1), however, all groups that are well-described by our definition (i.e. in which the proportion of known species is ≥2/3 the estimated total number of species) remain well-known over the full range of estimated total species richness values, and variance in the proportion of known species is also relatively low for most well-assessed marine groups (fig S1). Given that we focus most attention on

these well-known groups, we feel justified in using the midpoint of total species estimates. A further point of discrepancy occurs due to the continuing development of the World Register of Marine Species [S5], such that the number of described species now (2014 described) differs from those given in [S1] (2012 described) for many groups. However, there is a very close linear relationship between these two figures (linear model of log(2012 described) ~ log(2014 described), $R^2 = 0.99$) with a slope not significantly different from 1 ($b = 1.00$, 95% CI = 0.979—1.020). For consistency with [S1], we prefer to use 2012 described figures for calculations of the proportion of species known for each group, but use 2014 described figures to calculate proportions of IUCN-assessed species (see below).

Data on levels of taxonomic description for non-marine groups were taken using figures of 'currently catalogued' species for the number of described species, and 'estimated' species richness as the total predicted number of species, from Table 1 in [S2]. Where relevant, marine species were subtracted from each total, using the described and estimated numbers from [S1], amalgamated to the relevant groups used in [S2]. If the number of marine species described or estimated for a group approximated or exceeded the numbers in [S2] the group was assumed (for practical purposes) to be entirely marine and so was excluded from the non-marine analysis. For example, the sponges (Porifera) were excluded, because the number of non-marine species is so small compared to the number of marine species. Likewise, groups in which marine representatives are only a tiny fraction of all species, and which are not comprehensively represented in [S1] – for example the vascular plants, Tracheophyta – are considered for practical purposes to be entirely non-

marine. We amalgamated three categories of vascular plant – Magnoliophyta, Gymnosperms, and ferns and allies – used in [S2] into the single group Tracheophyta, following ITIS (www.itis.gov). Data from Table 2 in [S3], which gives the number of described species for a series of non-marine groups, as well as an estimate of the total number of species still to be discovered in each group, were used to supplement the non-marine dataset. We estimated the total number of species in each group as the number described plus the median of this final total to be discovered. Only groups that did not overlap those listed in [S2] were used. The full non-marine dataset comprises 1,463,813 described and 5,192,724 estimated species from 19 taxonomic groups (Table S1). Uncertainty in the proportion of species known within these non-marine groups is typically greater than that observed in the marine groups (fig S1), however with the exception of the highly uncertain estimates for non-marine Mollusca, again the best-known groups (taxonomically and in terms of conservation assessments) tend to remain reasonably well-known across the range of this uncertainty (fig S1).

Rates of conservation assessment

To derive numbers of marine and non-marine species assessed by the IUCN, we elected to use WoRMS [S5] as a list of marine species as it results in a more comprehensive coverage than obtained using the 'habitat' fields recorded within the IUCN database. We used the standard definition of 'marine' species, which includes all species listed in WoRMS with the habitat field including 'marine' and/or 'brackish', and assumed that all species in WoRMS with no recorded habitat affinity were marine. 9,777 names from the IUCN list could be matched to marine species

names in WoRMS, of which 9,554 match to a valid species name in one of the 88 groups listed in table S1. Taxonomic names with >1 IUCN assessment category (e.g. where IUCN names are considered as subspecies by WoRMS) were amalgamated to the relevant valid species-level WoRMS ID, and assigned the lowest degree of threat of any of the IUCN names associated with it (with any other IUCN classification taking precedence over Data Deficient). Thus, 97.7% of marine species names in the IUCN list are valid marine species *sensu* WoRMS and occur within one of the 88 marine taxonomic groups we consider.

We assume that all those species assessed by the IUCN and not identified by us as marine therefore constitute valid, non-marine species. We checked this by matching 19,153 non-marine IUCN species names in Kingdom Plantae to The Plant List (TPL [S5]) using the *Taxonstand* package [S6] in R [S7]. 17,881 of the IUCN plant names (93.4%) directly matched an accepted TPL name, and the 19,153 IUCN names pointed to 18,888 TPL names, suggesting a taxonomic inflation of 1.4%. The number of non-marine bird (Class Aves) names in the IUCN list (9,435) is also within 1% of our estimate of non-marine described species (9,349). Given that taxonomic disagreements are likely to be of a lesser magnitude than uncertainty around the total number of non-marine described species, we accept the IUCN taxonomy for non-marine species, resulting in 63,909 assessed species, of which 61,664 (96.5%) occur in the 19 non-marine groups for which we also have estimates of taxonomic description status (Table S1).

Supplemental References

S1. Appeltans, W., Ahyong, S. T., Anderson, G., Angel, M. V., Artois, T., Bailly, N., Bamber, R., Barber, A., Bartsch, I., Berta, A., et al. (2012). The magnitude of global marine species diversity. Curr. Biol. *22*, 2189–2202.

S2. Scheffers, B. R., Joppa, L. N., Pimm, S. L., and Laurance, W. F. (2012). What we know and don't know about Earth's missing biodiversity. Trends Ecol Evol *27*, 501–510.

S3. Costello, M. J., Wilson, S., and Houlding, B. (2012). Predicting total global species richness using rates of species description and estimates of taxonomic effort. Systematic Biology *61*, 871–883.

S4. Massó i Alemán, S., Bourgeois, C., Appeltans, W., Vanhoorne, B., De Hauwere, N., Stoffelen, P., Heughebaert, A., and Dahdouh-Guebas, F. (2010). The "Mangrove Reference Database and Herbarium." Plecevo *143*, 225–232.

S5. WoRMS Editorial Board (2014). The World Register of Marine Species. marinespecies.org. Available at: http://www.marinespecies.org/ [Accessed October 7th, 2014].

Supplemental Movie and Spreadsheet
Click here to download Supplemental Movie and Spreadsheet: TableS1.csv