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Research Article

Assessing body weight as a predictor of vulnerability for extinction in marine invertebrates

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ABSTRACT. In tetrapods, body weight (BW) is a reliable predictor of extinction risk as it is representative of their life cycle, physiology, and ecology: low BW species tend to be less vulnerable compared to larger ones. In marine fish, excepting elasmobranchs, sturgeon, and salmonids, this relationship is not statistically significant; and in marine invertebrates it is unknown. In this study, the BW was evaluated as a predictor of extinction vulnerability in marine invertebrates at two taxonomic levels, assuming that endangered species lists indicate true extinction risk. At the order level, a correlation was performed between BW and the proportion of species in conservation lists concerning the total number of species (TS) of 17 orders. At the species level, we compared the average BW of listed *versus* not listed species by fitting a logistic regression between the BW and the presence/absence of species in these lists. We found no relationship between TS and BW, but there was a significant difference in the BW of listed *versus* not listed species. The relationship between the BW and the presence/absence of species in conservation lists was weaker in marine invertebrates compared to that in tetrapods and fish. The BW is an unreliable predictor of extinction risk in marine invertebrates. Thus conservation efforts should focus on maintaining and restoring the microhabitat of invertebrate species.

Keywords: conservation lists; endangered species; body mass; extinction risk

INTRODUCTION

Throughout the evolution of life on earth, some taxonomic groups have disappeared more frequently than others. These groups have common heritable attributes that seem to contribute to their high risk of extinction (Damut, 1981; Gaston & Blackburn, 1995; Cardillo, 2003). Examples of such attributes are small population sizes, large-sized but infrequent litters or spawns, small distribution areas, a high degree of specialization and a large body mass (Pimm *et al*., 1988, McKinney, 1999). Of these, weight has been widely used to indicate the extinction risk of different taxa because it is easy to obtain and is representative of the life cycle, physiology, and ecology of an organism, body weight influences metabolic rate, individual growth, reproductive rate, population density and dispersal capacity, among other attributes (Damuth, 1981; Peters, 1983; Roy *et al*., 2001; Woodward *et al*., 2005; White *et al*., 2007).

According to some authors, there is a positive relationship between vulnerability and body weight in tetrapods (Pimm *et al*., 1988; Cardillo & Bromham, 2001; Del Monte-Luna & Lluch-Belda, 2003). In this group, small organisms (low body weight) are less susceptible to extinction than larger ones. Heavier species, in contrast, have a slower metabolism, lower growth rates, low fecundity, limited dispersal capacity and low population density (Purvis *et al*., 2000; White *et al*., 2007); therefore, they are less able to recover from drastic population changes compared to smaller species.

In the case of marine fish, body weight does not wholly explain vulnerability, which seems to be complicated by other underlying factors (Del Monte-Luna & Lluch-Belda, 2003). These authors argue that the

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relationship between weight and vulnerability in this group is particularly evident in large, long-lived, and anadromous species with low fecundity (*e.g.*, elasmobranchs, salmonids, and sturgeons). One possible explanation for the lack of a significant correlation between body weight and extinction vulnerability in fish is that the marine environment is less accessible to humans compared to the terrestrial environment, which gives marine species some protection (Del Monte-Luna & Lluch-Belda, 2003). Other authors attribute this lack of relationship to the greater difficulty in evaluating and taxonomically describing marine species than terrestrial species, leading to a shorter conservation list for marine species (Webb & Mindel, 2015).

In invertebrates, the relationship between body weight and extinction vulnerability is unknown. For example, extinction vulnerability of terrestrial gastropods is better explained by shell shape and size than by body weight because the shell plays an important role in microhabitat preference (Chiba & Roy, 2011).

The lack of studies on extinction risk in marine invertebrates is not consistent with their ecological relevance; reducing the abundance of some of these species through fishing or habitat destruction can negatively impact ecosystems. In recent decades, fishing pressure on marine invertebrates has increased, and some fisheries targeting this group have already exceeded sustainable limits of exploitation (Anderson *et al*., 2011). In pelagic ecosystems, fishing can reduce the efficiency of the "top-down" energy control that predators, such as squid, exert on lower trophic levels (Eddy *et al*., 2017). In benthic ecosystems, an excessive reduction in the biomass of low-trophic-level invertebrates, such as shrimp, may affect the size of third- and fourth-order predator populations (Eddy *et al*., 2017). Despite these ecological effects, no relationship has been found between these effects and the increase in extinction risk of marine invertebrates.

In general, marine invertebrates are rarely considered in conservation policies, and there is uncertainty in the application of criteria and assignment of categories to assess their vulnerability. Criteria used to classify conservation status of mammals, such as the relationship between weight and extinction risk, are commonly applied indiscriminately to phylogenetically distant groups, such as invertebrates (Regnier *et al*., 2009; McCauley *et al.*, 2015). This practice can result in underestimating or overestimating extinction vulnerability of numerous species.

The present work focused on analyzing whether there is a relationship between marine invertebrate body weight and extinction vulnerability, as indicated by the presence/absence of species in various international conservation lists. Based on previous findings, the relationship between both variables was expected to be similar to the relationship observed in fish. Establishing this relationship could allow identifying the determinant aspects of extinction susceptibility in marine invertebrates, which would be useful for prioritizing conservation and research efforts.

MATERIALS AND METHODS

Marine invertebrate body weight data were obtained from three sources: 1) scientific texts, which included specialized articles, textbooks, technical reports, and postgraduate theses; in some cases the individual weight of the species was derived from documented relationships between weight and height; 2) free databases available on the internet, and 3) direct measurements of specimens in the field and laboratory. With this information, a database was created containing the taxonomic classification of the species, conservation status, and data on their distribution and weight or length. The entire data set of the present study is available from the authors upon request.

The extinction risk data came from statistics of seven species conservation lists that are freely available online: 1) International Union for Conservation of Nature Red List (IUCN; www.redlist.org), 2) Mexican Official Standard 059 (www.sma.df.gob.mx), 3) National Council of Protected Areas of Guatemala (www.conap.gob.gt), 4) Endangered Species Act of the United States (www.fws.gov), and 5) the red lists of Endangered Species of Colombia, Venezuela and Andalusia, Spain. It was assumed that the presence of the species in these lists (in any category, except in the "Deficient Data" category) is related to their extinction vulnerability. Including only the species classified as high risk (*e.g.*, vulnerable and endangered) would substantially reduce the sample size.

With data on weight and extinction risks, two analyses were conducted: a descriptive analysis at the Order level, and quantitative analysis at the species level. It was assumed that any marine invertebrate species included in the conservation lists, regardless of their assigned category (except for "Deficient Data"), is vulnerable to extinction.

Analysis at the order level

An index developed initially by Del Monte-Luna & Lluch-Belda (2003) was used for tetrapods and fish to calculate the vulnerability index at the order level (ViO). This index was applied based on the number of species listed in an order divided by the total number of known living species of the same order, minus the species with insufficient information to perform an extinction risk assessment. The classification of the species according to their risk comes from each of the conservation mentioned above lists.

The vulnerability index (VI_O) is expressed by the following formula (Del Monte-Luna & Lluch-Belda, 2003):

$$\mathbf{VI_O} = \frac{\mathbf{EX_O} + \mathbf{CR_O} + \mathbf{EN_O} + \mathbf{VU_O} + \frac{\mathbf{LR}}{\mathbf{nt}}_{\mathbf{O}} + \mathbf{C_O} + \mathbf{LC_O}}{\mathbf{TNS_O} - \mathbf{DD_O}}$$

where: EX_O: number of extinct or probably extinct species in the order O; CR_O: number of species severely or critically endangered; EN_O: number of endangered species; E_O: number of threatened species, VU_O: number of vulnerable species; C_O: number of species under conservation or special management; LR/nt_O: number of species with low risk/near threatened; LC_O: number of species that are of least concern; TNS_O: total number of living species known in the order O; and DD_O: total number of species in order O with insufficient information to make an assessment of their extinction risk. Because the index is a proportion, it was transformed using the arcsine of the square root of the value to homogenize the variance of the data. The “Deficient Data” category is not a threat category and is included in the denominator because it contains species with insufficient abundance or distribution data to assess vulnerability.

The index gives a measure of the relationship between the total number of species in an order and the number of species in that orders that are on conservation lists. The vulnerability index is low when an order is very diverse, and few species are on conservation lists. In contrast, the index is high when an order is not very diverse, and all or almost its entire species are on conservation lists. The vulnerability index was compared with the average weight of all the species belonging to the order in question. A linear regression analysis was applied between the vulnerability index and the average weight per order.

Analysis at the species level

To determine whether marine invertebrate species present and absent in conservation lists differed in average weight, the difference between population means from independent samples was tested (Dytham, 2013), setting a significance level of 0.05.

A logistic regression model was applied to calculate the degree of dependence between the weight of the species and their presence or absence in the conservation lists. The average weight of each marine invertebrate species was used as the independent variable, and its presence or absence in the conservation lists was the dependent variable (1 = present, 0 = absent). In this analysis, it was also assumed that the presence of a species in conservation lists (in any category except in "Deficient Data") is related to its degree of extinction vulnerability. The logistic regression model parameters were estimated using the maximum likelihood method. This method estimates the values of the model parameters and compares the relative likelihood of these values to a range of different values (or hypotheses) through a “likelihood profile” (Hilborn & Mangel, 1997).

RESULTS

Body weight data were obtained for a total of 1040 species, of which 34 were listed, and 1006 did not belong to any list. The predominant invertebrate taxonomic group in the conservation lists was the cnidarians (63%), particularly corals, followed by arthropods (19%) and mollusks (18%). Cnidarians were not considered in the present work because they are mostly modular organisms, and it is not informative nor practical to obtain individual weight measurements. Within the lists, the "least concern" category had the highest number of species (38%). Species in this category were determined to have a large population and a wide distribution, so they were included in low-risk categories of conservation lists (Table 1).

The vulnerability index was calculated for 17 orders of the 34 species present in the conservation lists (body weight data are not available for all the species in the listed orders). The Order Pterioida had the highest index value of 0.07 (highest proportion of species listed). This order includes species of commercially important bivalves such as *Isognomon alatus*, *Pinctada mazatlanica*, and *Pinna rugosa*, among others.

When comparing the values obtained from the vulnerability index and the average weight per order, no significant relationship was found (Fig. 1). In contrast, a statistically significant difference ($P < 0.05$) was found between the average weights of the listed and non-listed species: the species not included in conservation lists had a higher body weight than the listed species (Fig. 2).

In the logistic regression model, the marine invertebrates had the highest beta coefficient value (related to the effect of body size on extinction risk) and the lowest likelihood value compared to those found in tetrapods and fish (Table 2). According to the likelihood profiles, the model best fit the tetrapods data; in this group, the coefficient value that maximized the likelihood had the lowest uncertainty. In contrast, the model was not very representative of the marine invertebrate data.

The likelihood profile had a larger variance (*i.e.*, greater uncertainty in the estimation of the parameters) and a lower likelihood value, indicating that a range of

Table 1. Number of marine invertebrate species by categories of the different regional and international conservation lists: Ex: extinct, CR: critical danger, EN: endangered, Vu: vulnerable, C: under conservation or special management, LR/nt: low risk or near threatened, LC: least concern, DD: data deficient.

Row/Categories	Ex	CR	EN	Vu	C	LR/nt	LC	DD	Total
Annelida	-	1	-	-	-	-	-	1	2
Arthropoda	-	4	2	8	-	2	162	89	267
Cnidaria	-	7	25	206	5	176	297	149	865
Echinodermata	-	-	-	-	1	1	1	2	5
Mollusca	4	3	10	43	12	3	68	98	241
Nemertea	-	-	-	-	-	-	-	1	1
Total	4	15	37	257	18	182	528	340	1381

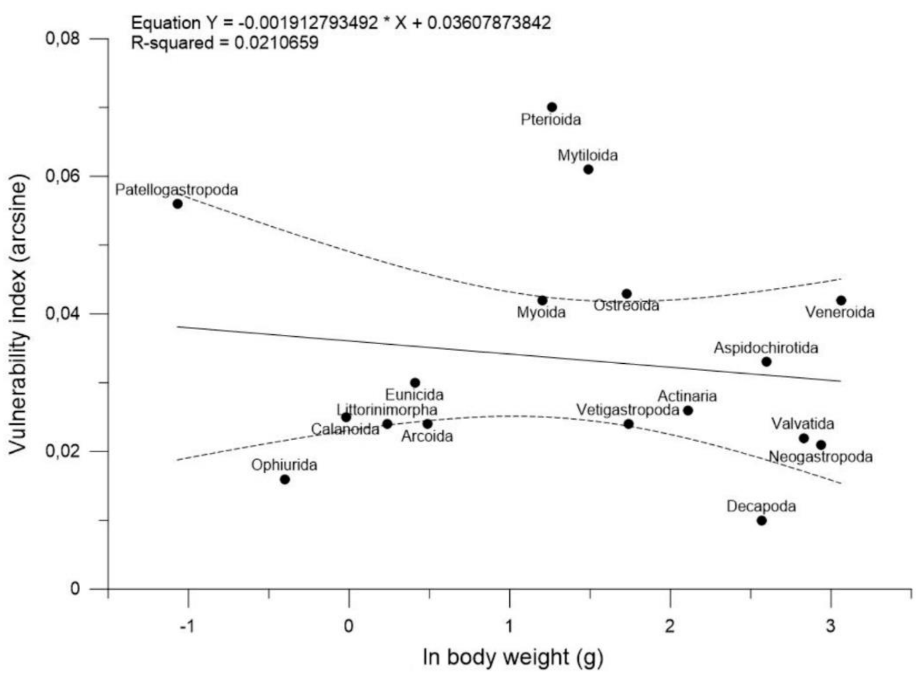

Figure 1. The relationship between body weight and the vulnerability index of the 17 evaluated orders of marine invertebrates. Dotted lines indicate confidence bounds at 95%.

different parameter values produced the same adjustment to the observed data (Fig. 3).

DISCUSSION

The percentage of marine invertebrate species on the conservation lists was small compared to other groups. Of the 1381 species of marine invertebrates present in the conservation lists that were reviewed, 38% of them were in the lowest risk category, and 24% were in the "Deficient Data" category. This result suggests that deficiencies may exist in assessments of the conservation status of unknown or little known marine invertebrate species (Cardoso *et al.*, 2011a, b).

In the conservation lists, there is a preference for evaluating large animal species because their wide ranges and high dispersal capacity make them easy sampling subjects (Cardoso *et al.*, 2011a). Examples of this bias are species of commercial interest and iconic or flagship species, preferred for their heavy body weight (*e.g.*, mysticetes, proboscideans, large cats, etc.) or positive public perception (*e.g.*, odontocetes, primates, phocids, Cardoso *et al.*, 2011b). In contrast, small species with narrow distribution ranges and limited dispersal capacity, as is the case for some marine invertebrates and especially endemic species, are less studied.

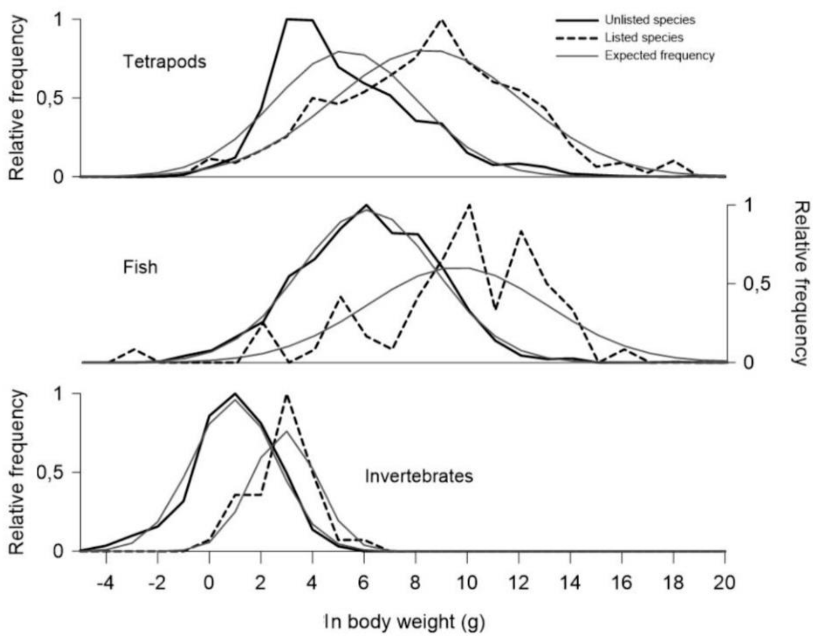

Figure 2. Comparison of the observed and expected relative frequencies (gray line) of the body weights of tetrapods, fish and marine invertebrates that were included in (dotted line) and not included (solid line) in different regional and international conservation lists.

Table 2. Results of the regression analysis and mean differences for tetrapods, fish and marine invertebrates. *Taken from Del Monte-Luna & Lluch-Belda (2003).

		Tetrapods*	Fish*	Marine invertebrates
Linear regression of the vulnerability index	Intercept	0.3	0.01	0.09
	Coefficient	0.06	0.07	0.07
Difference of population means		19.90	7.87	6
Logistic regression	Intercept	-3.71	-6.87	-4.8
	Coefficient	0.31	0.49	0.95
	Likelihood	1413	224	122

Thus, although extinct or threatened invertebrates have disappeared or may be the first to disappear, respectively, in the face of habitat alteration, they are not always considered to be a conservation priority by the scientific community (Regnier *et al*., 2009; Cardoso *et al*., 2011a). In groups such as mammals, birds, and amphibians, up to half of the known species have been evaluated. In contrast, 1% of marine invertebrates have been evaluated [http://cmsdocs.s3.amazonaws.com/summarystats/20173_Summary_Stats_Page_Documents/2017_3_RL_Stats_Table_1.pdf]. This taxo-nomic bias is also observed in the IUCN lists (Gaston & May 1992; McKinney, 1999; Lydeard *et al*., 2004).

Analysis at the order level

In tetrapods, there is a positive linear relationship between vulnerability and average body weight, while there is no clear trend in fish (Del Monte-Luna & Lluch-Belda, 2003). In the present work, we did not find a statistically significant relationship between the vulnerability index in marine invertebrates (species within different conservation lists) and the average weight of the orders to which they belong.

The marine invertebrate of the orders Decapoda, Littorinimorpha, Veneroida, and Neogastropoda had 89% of their species listed, which makes them the most vulnerable groups. These orders include some species of high weight, such as lobsters and mollusks with shells and/or large valves (*Tridacna gigas* and *Strombus gigas*), but vulnerability index values were not positively related to the average weight of the species within these Orders.

It is important to note that coral reefs are the most frequent invertebrate species in conservation lists, but

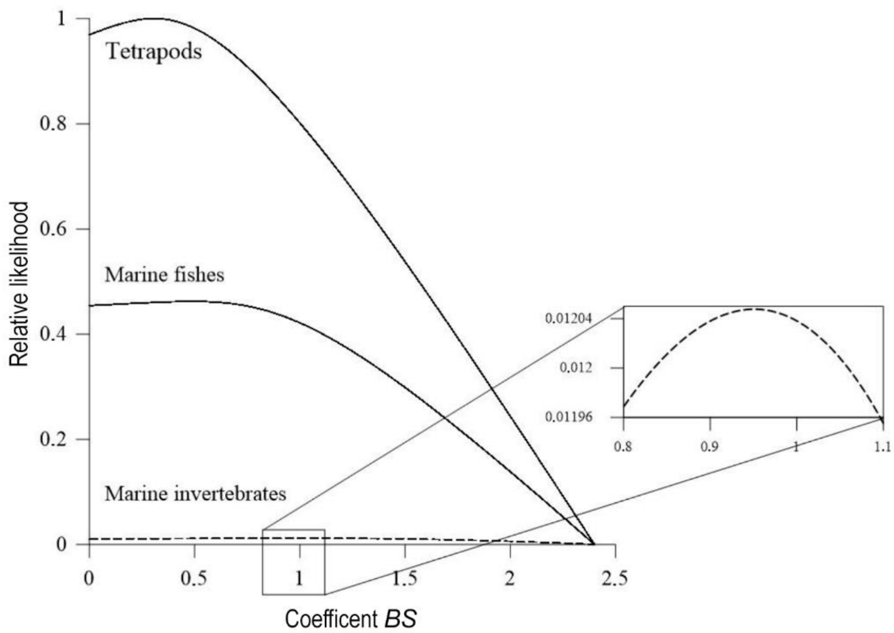

Figure 3. Comparison between likelihood profiles of the beta coefficient of the logistic regression (coefficient associated with weight) applied to body weight data and extinction risk in tetrapods (dashed line), fish (dotted line) and marine invertebrates (solid line). Continuous solid lines represent the confidence intervals of the coefficient in each group. Inner graph shows a close up of the likelihood profile for invertebrates.

they were not considered in the present analysis for methodological reasons. Corals have been affected by ocean warming and acidification, which lead to bleaching and susceptibility to diseases. Corals have also been affected by anthropogenic factors such as pollution (Huang & Roy, 2013). However, with the methodology used in this work, it was not possible to determine the degree of vulnerability because corals are modular organisms, and it does not make sense to measure individual weights.

If the orders of the listed corals were analyzed, it is likely that the values of the vulnerability index would be like the rest of the evaluated orders, except the Order Scleractinia, which stands out due to a large number of corals listed (838 species). This order has a vulnerability index of 0.41, which is high compared to the values obtained for the other groups. It is also likely that there is no relationship between vulnerability and weight because corals are small organisms that live in colonies that can vary considerably in size.

Analysis at the species level

Marine species on conservation lists tended to be heavier than those not listed, as it has also been demonstrated in tetrapods and fish (Del Monte-Luna & Lluch-Belda, 2003). This finding assumes that (1) the species that fall within the risk categories (extinct, critically endangered, endangered, vulnerable, threatened) are more susceptible to extinction, and that (2) the heavier species are more vulnerable and, therefore, tend to be more susceptible to being listed than the lighter species. However, according to the present work, the extinction vulnerability of marine invertebrates is not a direct function of weight. Additionally, it has been found that larger species tend to be more vulnerable to the introduction of predators or competitors and other anthropogenic factors, such as hunting and fishing because large sizes are selectively captured (Genner *et al*., 2009).

The difference in weight between the listed and unlisted species varied among tetrapods, fish, and invertebrates; the most significant difference was observed in the tetrapods, and the smallest difference was observed in marine invertebrates. The greatest difference between the means of these two histograms (how much they are separated due to body weight) was observed in the tetrapods, and the lowest difference was observed in marine invertebrates. Therefore, unlike tetrapods, the body weight of invertebrates does not appear to influence which species appear on conservation lists.

In the case of marine invertebrates that are commercially exploited, a relationship between extinction risk and body weight also has not been found. In this group, the main extinction risk factor is the market price, set according to accessibility and familiarity of the resource, followed by the geographic range and the density of the human populations near the fishing areas (Purcell *et al*., 2014).

Regarding the statistical uncertainty (appreciable in the likelihood profiles of parameter β, Fig. 3), the fit of the logistic model to the weight data and presence/absence data of the conservation lists was less precise for marine invertebrates than for fish. The confidence intervals of the parameter β in the profiles progressively increased from tetrapods to invertebrates, which indicates that there was more uncertainty in the weight-vulnerability relationship in the latter group. This result suggests that the weight of marine invertebrates does not significantly determine the presence of a species in the conservation lists. If these listings are a reliable reflection of the vulnerability of the species, then the weight would not be a good predictor of extinction risk in this group.

Vulnerability to extinction in marine invertebrates

Marine invertebrates are hypothesized to be less vulnerable than other groups because they have high fecundity and a life cycle that facilitates their dispersal (Carlton *et al.*, 1999; Myers & Ottensmeyer, 2005). Also, as in the case of fish, the marine environment provides some protection from anthropogenic factors, which reduces their vulnerability (Del Monte-Luna & Lluch-Belda, 2003). Over longer time horizons, it is believed that marine species may be less prone to disappear than terrestrial and freshwater species (Regnier *et al*., 2009) because the marine environment has presented fewer extinction events than terrestrial systems and because the extinctions have been less severe in terms of the number of groups affected (Cardoso *et al.*, 2011a). Additionally, most of the recent marine extinctions that have been documented, from 1500 AD on, were not exclusively marine species, but organisms that spent part of their lives outside the sea or in another aquatic environment (Del Monte-Luna *et al*., 2007; Harnik *et al*., 2012; McCauley *et al*., 2015).

The findings of the present study suggest that, at the species level, extinction vulnerability in marine invertebrates is not determined by weight but by other factors. For example, in terrestrial gastropods, an important factor in their vulnerability is the shape of their shell because it is involved in microhabitat selection (Chiba & Roy, 2011). However, the effect of shell shape on extinction vulnerability in marine mollusks is unknown. Carlton (1993) argued that marine invertebrates with a restricted distribution, limited dispersal capacity and/or habitat specialization tend to be more susceptible to extinction. The only two verifiable cases of global extinction of marine invertebrate species were due to alterations in a remarkably restricted habitat (*Littoraria flammea* and *Cerithidea fuscata*).

Considering the causes of recent marine extinctions, it could be said that large organisms, such as mammals and birds, are more susceptible to exploitation by humans (Dulvy *et al*., 2003). Whereas small species, such as invertebrates and algae, are more affected by habitat alterations and secondarily, fishing, especially fishing of naturally rare and high-value species per unit of weight (Branch *et al*., 2013). Thus, extinction vulnerability in marine invertebrates could be more related to geographical distribution.

In conclusion, it is suggested that marine invertebrate body weight is an unreliable predictor of extinction vulnerability. Taking into account the cases of global disappearances in marine invertebrates and the species found in conservation lists worldwide, the geographical distribution may be more closely related to vulnerability. It is necessary to investigate other possible predictors to conduct a correct and precise evaluation of extinction risk in marine invertebrates. These investigations could help identify which species require protection measures and could help prioritize conservation efforts.

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