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Updated extinction risk assessments of Madagascar's freshwater decapod crustaceans reveal fewer threatened species but more Data Deficient species

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Abstract

We report here on a new systematic assessment of the extinction risk of all 64 species of Malagasy freshwater decapods (freshwater crabs, crayfish, and freshwater shrimps). In Madagascar, this group has a richer species diversity and a higher endemism rate than comparable countries in the Afrotropical region. Recent exploration and new taxonomic studies have shown that Madagascar has 17 species of freshwater crabs (Potamonautidae), seven species of crayfish (Parastacidae), and 40 species of freshwater shrimps (Atyidae and Palaemonidae) most of which are endemic. These numbers are expected to rise as exploration continues. The main threats to Madagascar's freshwater decapod fauna are driven by a high human population density, increasingly disturbed habitats, extreme fragmentation, and poor land use practices.

The extinction risk status of each species of Madagascar's freshwater crabs, crayfish, and freshwater shrimps has been either assessed or reassessed against the IUCN (2012) Red List criteria. We conclude that one species of Malagasy freshwater decapod is Endangered, four are Vulnerable, 30 are Least Concern, and 28 are Data Deficient. The present study is a first step toward developing a conservation strategy for this fauna because the results will be used to update IUCN Red Lists and to identify Key Biodiversity Areas for Madagascar's threatened freshwater decapods. An understanding of the extinction risk of Madagascar's endemic freshwater decapod crustacean species is needed to underpin conservation planning and priority setting in this global biodiversity hotspot, and to complement existing information on the island's threatened vertebrates and invertebrates.

Key words: Potamonautidae, Parastacidae, Atyidae, Palaemonidae, Red List, KBAs, conservation

Résumé détaillé

Nous rapportons ici une nouvelle évaluation systématique du risque d'extinction des 64 espèces de décapodes d'eau douce malgaches (crabes, écrevisses et crevettes). A Madagascar, ce groupe a une diversité spécifique plus riche et un taux d'endémisme plus élevé que ceux des pays comparables de la région afro tropicale. Une exploration récente et de nouvelles études taxonomiques ont montré que Madagascar dispose de 17 espèces de crabes d'eau douce (Potamonautidae), sept espèces d'écrevisses (Parastacidae) et 40 espèces de crevettes d'eau douce (Atyidae et Palaemonidae), dont la plupart sont endémiques. On prévoit que ces chiffres pourraient augmenter dans la mesure où l'exploration continue.

Les principales menaces qui pèsent sur la faune de décapodes d'eau douce de Madagascar résultent d'une forte densité de la population humaine, des habitats de plus en plus perturbés, de la fragmentation extrême, et des mauvaises pratiques

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d'utilisation des terres. L'état de conservation de chacune des 17 espèces de crabes d'eau douce, des sept espèces d'écrevisses, et des 40 espèces de crevettes d'eau douce a été soit évalué, soit réévalué par rapport aux critères de la Liste Rouge de l'IUCN (2012). Nous concluons qu'à Madagascar une espèce de décapodes d'eau douce a le statut En Danger, quatre Vulnérables, 30 en Préoccupation Mineure, et 28 en Données Insuffisantes. La présente étude est une première étape vers l'élaboration d'une stratégie de conservation de cette faune, car les résultats seront utilisés pour mettre à jour les listes rouges de l'UICN et pour identifier les zones clés de biodiversité de ces décapodes d'eau douce menacés de Madagascar. Une compréhension de l'état de conservation des espèces de crustacés décapodes d'eau douce endémiques de Madagascar est nécessaire en vue de soutenir la planification de la conservation, d'établir des priorités dans ce hotspot de la biodiversité mondiale, et de compléter les informations existantes sur les vertébrés et les invertébrés menacés de l'île.

Mots clés : Potamonautidae, Parastacidae, Atyidae, Palaemonidae, Liste Rouge, KBA, conservation

Introduction

This overview of the conservation status of Madagascar's freshwater decapod fauna (freshwater crabs, crayfish, and freshwater shrimps) is part of a joint project between the International Union for the Conservation of Nature (IUCN) and Conservation International to accelerate the conservation of Madagascar's threatened freshwater biodiversity. The conservation assessments of the four families of Malagasy freshwater decapods presented here apply the IUCN's Red List Categories and Criteria (version 3.1) (IUCN, 2012) to assign species to threat categories using quantitative data to estimate the relative risk of extinction for each species at the global scale (IUCN, 2012). The project aims to integrate the freshwater decapod Red List assessments with those of a representative portion of the island's other freshwater groups (mollusks, dragonflies, fish, and plants) and use the combined data to identify, delineate, and validate new Key Biodiversity Areas (KBAs) based on the needs of threatened freshwater organisms. The IUCN Red List of Threatened Species (hereafter referred to as the IUCN Red List) and freshwater KBAs are two powerful and internationally respected conservation tools that will be applied for the first time to aid in the protection of Madagascar's freshwater ecosystems (IUCN, 2016). The new KBAs will form the basis of a protected areas network for Madagascar's freshwater biodiversity. The prioritization of species for conservation action based on information on their distribution and their threats will help guide the development of conservation recovery plans. These tools will enable political and economic decision makers within Madagascar to develop biodiversity and conservation priorities for their freshwater ecosystems.

The results presented here for Madagascar's freshwater decapods take advantage of the recent surge of interest in this fauna in the form of collaborative explorations, taxonomic treatments, and extinction risk assessments by specialists (Cumberlidge *et al*., 2009; De Grave *et al*., 2014; Richman *et al*., 2014). Knowledge of the Malagasy freshwater decapod fauna has increased in all three groups (from five species in three genera to 17 species in eight genera for freshwater crabs, from six to seven species for crayfish, and from 34 to 40 species for freshwater shrimps). There is every prospect that the species counts in all of these groups will increase further as exploration continues. The high degree of endemism shown by the 64 species of Malagasy freshwater decapods (100% at the genus and species levels for crayfish and freshwater crabs, and 58% of species and 33% of genera for freshwater shrimps) is a characteristic that they share with many other freshwater organisms from this long-isolated tropical island (Cumberlidge *et al*., 2009; De Grave *et al*., 2014; Richman *et al*., 2014). The extensive loss of the island's freshwater habitats that is currently occurring is therefore of great concern for the future security of this fauna.

The island's diverse freshwater ecosystems and its unique wildlife are ultimately threatened by the activities of the rapidly growing human population that encroach on freshwater habitats in all parts of the island: the eastern humid rain forests, the drier and cooler central highlands and western savannas, and the arid and semi-arid southwestern areas. In all of these ecosystems, freshwater decapods live in lakes, streams, and rivers, as well as in adjacent terrestrial habitats such as forest floors, rocky crevices, and rain forest phytotelmata (Cumberlidge *et al*., 2002, 2005).

Until recently, all three groups of Malagasy freshwater decapods were poorly represented in museum collections and so for many species there is no reliable historical baseline against which to judge trends in distributions or populations. Encouragingly, the past two decades have seen a resurgence of interest in Madagascar's freshwater ecosystems, and biotic surveying of most groups of organisms

has intensified throughout the island. Notably, Steven M. Goodman (Field Museum of Natural History, Chicago, USA, and Association Vahatra Association, Antananarivo, Madagascar) has compiled substantial collections of freshwater decapods from all parts of the island with the result, for example, that the Field Museum now houses the world's most extensive assemblage of Malagasy freshwater crabs. This wealth of recent material has formed the basis of the taxonomic revisions that have contributed to our present knowledge of species diversity on the island and has enabled the IUCN Red List assessments reported on here (Cumberlidge & Boyko, 2001; Cumberlidge & Sternberg, 2002, 2003; Cumberlidge *et al*., 2002, 2007, 2008, 2009, 2015a, 2015b; Reed & Cumberlidge, 2006; Cumberlidge, 2008a, 2008b, 2010; Cumberlidge & Meyer, 2009; Meyer *et al*., 2014). Convincing evidence is now emerging from recent phylogenetic studies (Crandall *et al*., 2000; De Grave *et al*., 2009; Daniels *et al*., 2015) that the four families of Malagasy freshwater decapods each represent a unique lineage with a distinct history that reflects their present-day relationships with neighboring southern continental faunas and is of considerable biogeographic significance. The remarkable diversity, richness, endemism, and phylogenetic uniqueness of Madagascar's freshwater decapod fauna and the immediate nature of the threats make the conservation of these animals a matter of the highest priority.

Freshwater ecosystems globally are undervalued in terms of the biodiversity they support and the services they provide to people. For example, it is estimated that almost 75% of the world's freshwater wetlands have been lost during the last century as a result of their neglect and misuse (Davidson, 2014). This loss has been accompanied by a global decline in the populations of freshwater species at a rate of loss that is almost double that of terrestrial and marine species (McLellan *et al*., 2014). Today, about one-third of all freshwater species on the IUCN Red List are threatened with extinction (IUCN, 2014a, b). The decline in freshwater habitats and in the freshwater species that depend on them is clearly visible in Madagascar whose extensive wetlands (rivers, streams, and lakes) are heavily disrupted and in generally poor condition (Conservation International, 2014). It is either the degradation or the complete loss of habitat that accounts for the high levels of threat to Madagascar's freshwater species (Darwall *et al*., 2009). For example, the loss of 80% of the original (pre-human) forest cover in Madagascar for agriculture, grazing, and brick making has resulted in water resource degradation, habitat loss, soil loss, desertification, and biodiversity erosion. Remarkably, the 2004 IUCN Red List assessment of Madagascar's freshwater fish found that 85% of the island's endemic species were threatened with extinction, that three species were already Extinct, and that another species was Extinct in the Wild (IUCN, 2004, 2014b). This represents one of the highest levels of threat to a species group at the national scale anywhere in the world.

The above reasons underline the need for the establishment of new protected areas for freshwater ecosystems that would represent a powerful tool for the conservation of these habitats. However, terrestrial wetlands are underrepresented in the present system of protected areas in Madagascar (Conservation International, 2014) and in continental Africa (Darwall *et al*., 2011). Encouragingly, the Government of Madagascar has recently reiterated its commitment to triple the protected area coverage of land and to ensure the effective management of all of its protected areas (IISD, 2014). We aim here to contribute to greater representation of freshwater habitats within the protected area network in Madagascar, and to the more effective protection of the freshwater species found within the existing protected areas.

Methods

The extinction risk of each of Madagascar's 64 species of freshwater decapods was evaluated using the IUCN Red List Categories and Criteria (version 3.1) (IUCN, 2012). Species were assigned to one of eight categories to indicate their relative extinction risk: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data Deficient (DD). Species assessed as VU, EN, or CR are described as threatened and face the highest risk of extinction in the wild. LC species are those with the lowest risk of extinction and these are typically common and widespread. DD species are those with insufficient information to assess their extinction risk. The reassessments and new assessments of the freshwater crabs and crayfish of Madagascar reported here used the IUCN Red List Categories and Criteria (version 3.1) (IUCN, 2012), and update the most recent global assessments of these two groups made in 2008 and 2010, respectively (Cumberlidge *et al*., 2009; Richman *et al*., 2014). The freshwater shrimps were assessed globally in 2013 using the IUCN Red List categories and criteria (version 3.1)

(IUCN, 2012; De Grave *et al*., 2014) and it was not considered necessary to update the extinction risk assessments of the 40 Malagasy species included here during the workshop in Madagascar in 2016.

Before publication on the IUCN Red List, the extinction risk assessments presented here have all been subjected to vigorous peer review by the IUCN Species Survival Commission's Freshwater Crustacean Specialist Group, the IUCN Freshwater Biodiversity Unit, and the IUCN Red List Unit. Species were evaluated against all five of the IUCN Red List criteria (IUCN, 2012) and the final category assigned for each species was based on the highest threat category met for any of the criteria. Each criterion investigates different factors relating to extinction risk and the assessment process uses data on geographic range and population size and trends, in combination with information on life history, population structure, and threats to the species. The geographic range was estimated using the extent of occurrence (EOO) (the area contained within the minimum convex polygon around all sites of present occurrence) and/or the area of occupancy (AOO) (the area within the EOO that is actually occupied by the taxon, estimated by overlaying a 2 x 2 km grid and summing the area of occupied cells). GeoCAT (Bachman *et al*., 2011) was used to calculate EOO and AOO measurements from point locality data. Locations were defined as areas in which a single threatening event (based on the primary threat to the species) could rapidly affect all individuals of the species present (IUCN Standards and Petitions Subcommittee, 2016). Very little population data were available for most species other than qualitative estimates based on the number of sites at which a species was present and its relative abundance at each site. Maps of species distributions were produced using ArcGIS software by ESRI. Assessments were made using information from the published and grey literature and from the personal knowledge of the expert assessors that were then reviewed by independent specialists at the workshop in Madagascar in 2016.

Results

The results of the application of the IUCN Red List protocols to Madagascar's 64 species of freshwater decapods are presented in Tables 1 and 2. Table 1 lists the seven species of crayfish and the 17 species of freshwater crabs (in eight genera) with their extinction risk category, while Table 2 lists the assessments for the two families of freshwater shrimps. These tables also serve

Table 1. Checklist of the crayfishes and freshwater crabs of Madagascar (Parasticidae, Potamonautidae). Extinction risk category is derived using the IUCN (2012) Red List criteria. EN, Endangered; VU, Vulnerable; LC, Least Concern; DD, Data Deficient.

Family	Species	RL Category (2009)	Criteria	RL Category (2016)	Criteria
Parastacidae	*Astacoides crosnieri*	DD		VU	B1ab(iii,v)
Parastacidae	*Astacoides hobbsi*	DD		VU	D2
Parastacidae	*Astacoides madagascariensis*	DD		LC	
Parastacidae	*Astacoides petiti*	DD		DD	
Parastacidae	*Astacoides betsileoensis*	EN	B1ab(iii)	VU	B1ab(iii)+B2ab(iii)
Parastacidae	*Astacoides caldwelli*	EN	B1ab(iii)	VU	B1ab(iii)
Parastacidae	*Astacoides granulimanus*	LC		LC	
Potamonautidae	*Malagasya goodmani*	DD		DD	
Potamonautidae	*Marojejy longimerus*	DD		DD	
Potamonautidae	*Skelosophusa eumeces*	DD		DD	
Potamonautidae	*Skelosophusa gollardi*	DD		DD	
Potamonautidae	*Skelosophusa prolixa*	DD		DD	
Potamonautidae	*Foza raimundi*	LC		LC	
Potamonautidae	*Hydrothelphusa agilis*	LC		LC	
Potamonautidae	*Hydrothelphusa bombetokensis*	LC		LC	
Potamonautidae	*Hydrothelphusa goudoti*	LC		LC	
Potamonautidae	*Hydrothelphusa madagascariensis*	LC		LC	
Potamonautidae	*Hydrothelphusa vencesi*	LC		LC	
Potamonautidae	*Malagasya antongilensis*	LC		LC	
Potamonautidae	*Boreathelphusa uglowi*	VU	B1ab(iii) D2	EN	B1ab(iii)
Potamonautidae	*Madagapotamon humberti*	VU	D2	LC	
Potamonautidae	*Foza manonae*	NA		DD	
Potamonautidae	*Glabrithelphusa angene*	NA		DD	
Potamonautidae	*Foza ambohitra*	NA		LC	

Table 2. Checklist of the freshwater shrimps of Madagascar (Atyidae, Palaemonidae). Conservation status is derived using the IUCN (2012) Red List criteria. DD, Data Deficient; LC, Least Concern. Data from De Grave *et al*. (2014).

Family	Species	RL Category (2014)
Atyidae	*Caridina crurispinata*	DD
Atyidae	*Caridina edulis*	DD
Atyidae	*Caridina lamiana*	DD
Atyidae	*Caridina lipalmaria*	DD
Atyidae	*Caridina norvestica*	DD
Atyidae	*Caridina parvocula*	DD
Atyidae	*Caridina petiti*	DD
Atyidae	*Caridina steineri*	DD
Atyidae	*Caridina troglophila*	DD
Atyidae	*Caridina unca*	DD
Atyidae	*Monsamnis carpolongus*	DD
Atyidae	*Parisia dentata*	DD
Atyidae	*Parisia edentata*	DD
Atyidae	*Parisia macrophthalma*	DD
Atyidae	*Parisia microphthalma*	DD
Atyidae	*Typhlopatsa pauliani*	DD
Atyidae	*Atyoida serrata*	LC
Atyidae	*Caridina angulata*	LC
Atyidae	*Caridina brachydactyla*	LC
Atyidae	*Caridina calmani*	LC
Atyidae	*Caridina gracilirostris*	LC
Atyidae	*Caridina hova*	LC
Atyidae	*Caridina isaloensis*	LC
Atyidae	*Caridina natalensis*	LC
Atyidae	*Caridina serratirostris*	LC
Atyidae	*Caridina typus*	LC
Atyidae	*Caridina xiphias*	LC
Palaemonidae	*Macrobrachium glabrum*	DD
Palaemonidae	*Macrobrachium hildebrandti*	DD
Palaemonidae	*Macrobrachium petiti*	DD
Palaemonidae	*Macrobrachium therezieni*	DD
Palaemonidae	*Macrobrachium australe*	LC
Palaemonidae	*Macrobrachium dolichodactylus*	LC
Palaemonidae	*Macrobrachium idae*	LC
Palaemonidae	*Macrobrachium idella*	LC
Palaemonidae	*Macrobrachium lar*	LC
Palaemonidae	*Macrobrachium lepidactylus*	LC
Palaemonidae	*Macrobrachium patsa*	LC
Palaemonidae	*Macrobrachium rude*	LC
Palaemonidae	*Macrobrachium scabriculum*	LC

as the most up to date species checklists for the four families of freshwater decapods found on the island. Changes of Red List extinction risk category from the last assessments of the freshwater crabs and crayfish made in 2008 and 2010, respectively, are also shown in Table 1. The category changes made to the extinction risk assessments affect six species of crayfish (*Astacoides betsileoensis* Petit, 1923, *A. caldwelli* (Bate, 1865), *A. crosnieri* Hobbs, 1987, *A. hobbsi* Boyko, Ravoahangimalala, Randriamasimanana & Razafindrazaka, 2005 and *A. madagascariensis* (Milne-Edwards & Audouin, 1839), and two species of freshwater crabs (*Boreathelphusa uglowi* (Cumberlidge & Sternberg, 2002), and *Madagapotamon humberti* (Bott, 1965). These changes include downlisting two EN species to VU and one VU species to LC, and uplisting one VU species to EN (Table 1). These are non-genuine changes resulting from new locality data and do not imply actual improvements and deteriorations in extinction risk.

Crayfish

The reassessments of the seven species of crayfish from Madagascar are as follows: four are VU (*Astacoides betsileoensis*, *A. caldwelli*, *A. crosnieri*, and *A. hobbsi*), two are LC, one is DD, and none are NT, EN, CR, EW, or EX. Two of the VU species (*A. betsileoensis* and *A. caldwelli*) are downlisted from EN (Jones, 2010a, 2010b) to VU. The four threatened VU species of crayfish are categorized based on their restricted geographic ranges using criterion B of the IUCN Red List categories and criteria (IUCN, 2012). All four species have an EOO of less than 20,000 km^2 (B1) (and an AOO of less than 2,000 km^2 (B2) in the case of *A. hobbsi*), all occur in 10 or fewer locations (subcriterion a), and all are experiencing continuing declines in the area, extent and/or quality of their habitat [subcriterion b (iii)] (and in the number of mature individuals [subcriterion b (v)] in *A. crosnieri*). Continuing declines were inferred if the habitat is threatened by agricultural encroachment and not in a protected area, or if the habitat is within a protected area but is still subject to anthropogenic impacts such as pollution, habitat disturbance, and the spread of invasive species. The VU assessment for *A. hobbsi* is based on its very restricted population (using criterion D2 of the IUCN Red List categories and criteria [IUCN, 2012]) and because this species is considered to be vulnerable to plausible threats that could quickly lead to it becoming CR or even EX.

Freshwater crabs

The reassessments and new assessments of the 17 species of freshwater crabs from Madagascar are as follows: one is EN (*Boreathelphusa uglowi*), nine are LC, seven are DD, and none are NT, VU, CR, EW, or EX. One of the LC species (*Madagapotamon humberti*) is downlisted from VU (Cumberlidge, 2008a). One of the three species that is assessed for the first time here (*Foza ambohitra* Cumberlidge & Meyer, 2009) is LC based on recently collected

material from a new locality in a protected area (Ankarana Special Reserve) that increased its original EOO (distributional range). The other two species (*Glabrithelphusa angene* Meyer, Cumberlidge & Koppin, 2014 and *F. manonae* Cumberlidge**,** Klaus, Meyer, & Koppin, 2015) are DD due to a lack of basic information. It is encouraging that half of the Malagasy freshwater crab fauna (nine out of 17 species) is LC, including all five species of *Hydrothelphusa* Milne-Edwards, 1872, plus *F. raimundi* Reed & Cumberlidge, 2006, *F. ambohitra* Cumberlidge & Meyer, 2009, *Malagasya antongilensis* (Rathbun, 1904), and *Madagapotamon humberti*. *Boreathelphusa uglowi* is uplisted from VU (Cumberlidge, 2008c; Cumberlidge *et al*., 2009) to EN because it has an EOO of less than 5,000 km^2 (B1), is found in five or fewer locations (subcriterion a), and is experiencing continuing declines in the area, extent and/or quality of its habitat [subcriterion b(iii)]. The downlisting of *M. humberti* from VU (Cumberlidge, 2008a, Cumberlidge *et al*., 2009) to LC is due to its recent collection from a number of new localities in Antsiranana Province all within protected areas (Ankarana Special Reserve, Montagne des Français Reserve, Orangea Reserve, and Analamerana Special Reserve) (Cumberlidge *et al*., 2015a). The seven DD species that are too poorly known to even carry out an extinction risk assessment are *Malagasya goodmani* (Cumberlidge, Boyko & Harvey, 2002), *Marojejy longimerus* (Cumberlidge, Boyko & Harvey, 2002), *Skelosophusa gollhardi* (Bott, 1965), *S. prolixa* Ng & Takeda, 1994, *S. eumeces* Ng & Takeda, 1994, *F. manonae,* and *G. angene*.

Freshwater shrimps

Data on the extinction risk of the 40 species of Malagasy freshwater shrimps assessed globally in 2013 using the IUCN Red List Categories and Criteria (version 3.1) (IUCN, 2012) (De Grave *et al*., 2014) revealed that the Atyidae includes 11 LC and 16 DD species, while the Palaemonidae includes nine LC and four DD species. It is encouraging that half of Madagascar's freshwater shrimp fauna is LC and not threatened with immediate extinction, but discouraging that the other half are too poorly known to assess. While no species of Malagasy freshwater shrimp is in any of the threatened categories (De Grave *et al*., 2014), this may change as the large numbers of DD species become better known.

Discussion

Madagascar's freshwater decapod fauna is undoubtedly rich in comparison with other similar-sized and better-studied areas of Africa. For example, both South Africa (1,222,000 km^2, 19 species, one genus) and Angola (1,248,000 km^2, nine species, one genus) have a territorial area of about twice that of Madagascar (587,040 km^2), but both have fewer genera and species when compared to Madagascar (17 species, eight genera) (Cumberlidge & Tavares, 2006; Cumberlidge & Daniels, 2007; Cumberlidge *et al*., 2009). Similarly, South Africa and Angola each have fewer species of freshwater shrimps (13 and six species, respectively) than Madagascar (which has 40 species), but Madagascar (seven genera) has a significantly higher richness at the genus level than both South Africa and Angola (three genera each) (De Grave *et al*., 2014). Although freshwater crayfish are not native to continental Africa, Madagascar's parastacid species richness (seven species in one genus) compares well with the crayfish fauna of the entire continent of South America (12 species in three genera) but poorly with that of Australia (124 species, 11 genera). The high degree of endemism shown by Madagascar's freshwater decapods is similar to the pattern shown by several other invertebrate and vertebrate groups, and reflects the long absence of biotic exchange between the island and the mainland that has resulted in genetic isolation and remarkable radiations within Madagascar's fauna and flora.

Approximately 80% of Madagascar's freshwater crab species are restricted to the island's northern province of Antsiranana (43,406 km²) which includes forested mountains, dry forests, and karst landscapes but represents only about 8% of the island's area. Crayfish are found in more than half of the island's freshwater habitats, but their range is restricted to forested mountains with cool streams and rivers in just four provinces (Antananarivo, Toamasina, Fianarantsoa, and Toliara) in an area of between 86,683 and 122,960 km^2 or 15-21% of the island. Madagascar's freshwater shrimp species include those that are thought to be found throughout the island, those whose distribution is restricted to a part of the island, and those whose distribution also includes continental Africa and some of the nearby Indian Ocean islands.

Madagascar's remarkable freshwater decapods fauna appears at first sight to be relatively unthreatened because about half (47%) of its species are LC, and only five of its 64 species (8%) are threatened with extinction. However, this may

be a significant undercount of threatened species because 28 out of its 64 species (44%) are too poorly known to assess their extinction risk. These DD Malagasy species of freshwater decapods introduce an element of uncertainty into the conservation planning process because their extinction risk (when eventually assessed) may either increase or decrease the number of threatened species (VU, EN, or CR), or it may not change current estimates if all of these species prove to be LC. However, it is likely that further surveying will reveal that many of the DD species should be assigned to a threatened category because they are truly single-locality endemics with a very narrow distributional range, a profile typical of many of the species currently in threatened categories worldwide (Cumberlidge *et al*., 2009). Clearly, the threatened and DD species of endemic Malagasy freshwater decapods present obvious foci for future ecological fieldwork, biotic inventories, and conservation prioritization activities.

Several important questions remain unanswered due to the lack of data. Those species that are known from a very small EOO and/or a small population may either be naturally restricted and difficult to find, or they may be the remnants of a more abundant widespread population that is now in sudden decline due to habitat loss or other impacts. This can be tested with more intensive sampling coupled with a study of population genetic data (Buhay & Crandall, 2005). Clearly, more surveying for freshwater decapods is needed, especially in those areas where threatened or DD species are known to occur, and up to date data on habitat requirements and population trends need to be gathered. It is clear that recovery plans need to be developed for the five threatened species of crayfish and freshwater crabs found in Madagascar and that studies on the 28 species of DD species in all three groups of freshwater decapods need to be intensified. The DD assessments included in this work are all based on a lack of information of the true distribution of the species. That is, we recognize that the area where a DD species is currently known from (usually only one locality) is not necessarily it is true overall range. In the event that further repeated surveying confirms that the species is indeed found only in a one locality then the new data would allow further analyses that may result in a different extinction risk assessment. It should be emphasized that DD does not mean that a species is not of conservation concern, only that we do not have sufficient information to estimate its extinction risk. Indeed, in many cases it is recommended that DD species be treated as threatened.

Threats to Madagascar's aquatic organisms and their habitats include invasive alien species. For example, more than 90% of the freshwater fish biomass comprises exotic species, and the invasive parthenogenetic marbled crayfish (marmorkrebs, *Procambarus fallax virginalis*) has become established in only a few years (Jones *et al*., 2009). Marbled crayfish pose a special problem on Madagascar because they can establish a new population from a single individual, and because they have a high reproductive rate. Other threats to aquatic habitats include deforestation because the remaining forests are seriously threatened by encroachment and illegal produce extraction. It is of concern that immediate threats to the island's aquatic habitats also include pesticides, local climate change, rainwater acidification, and silt loads from increased erosion.

The results of the extinction risk assessment of the entire Malagasy amphibian fauna (Stuart *et al*., 2004) indicate that these animals are far more threatened than the freshwater decapods. For example, 140/309 amphibian species (45%) were assessed as threatened with extinction (CR, EN, or VU) (vs. 5/64 species (8%) of freshwater decapods), but it is encouraging that no extinctions have been reported for either of these groups. Malagasy amphibians are also much better known than freshwater decapods with only 19/309 (6%) of species of amphibians DD (compared to 44% DD for freshwater decapods), while similar proportions of species of amphibians (131/309, 42%) and freshwater decapods (47%) are LC and not currently threatened with extinction.

The conservation of freshwater decapods depends on preserving large enough patches of natural freshwater habitat to maintain good water quality because many species are sensitive to polluted or silted waters and do not survive exposure (Bahir *et al*., 2005). It is therefore of great concern that water quality is deteriorating even in key natural habitats in Madagascar. The Promise of Sydney (IISD, 2014) notes that:

> "*Freshwaters are often only incidentally included as part of protected areas, or as borders to protected areas, without representative support for their management and conservation*", and recommends that: "*Countries give careful attention to ensuring that protected areas are identified and managed to conserve species and ecological processes across the biomes of land, freshwater, and marine*".

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