New Insights on Biodiversity and Conservation of Amphidromous Shrimps of the Indo-Pacific islands (Decapoda: Atyidae: Caridina)

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CHAPTER 11: New insights on biodiversity and conservation of amphidromous shrimps of the Indo-Pacific islands (Decapoda: Atyidae: *Caridina*).

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Abstract

Amphidromous shrimps of the genus *Caridina* (Crustacea: Decapoda: Atyidae) are essential components of the tropical insular freshwater ecosystems. Due to an extremely confused taxonomy, their biodiversity is poorly known, and their conservation status cannot be properly assessed. However, thanks to recent advances of integrative taxonomy, the systematics of this genus progressively becomes clearer, allowing us to draw conclusions about their biogeography and conservation biology. In this chapter, we 1) review the current state of knowledge of amphidromous *Caridina* diversity in the light of the latest results of integrative taxonomy on this model, 2) review the threats faced by *Caridina* in Indo-Pacific Islands, and 3) discuss how integrative taxonomy approaches can inform and support programs designed to limit the impacts of threatening processes on the diversity of *Caridina*. Finally, we provide recommendations for the conservation of these species and their habitats.

11.1 Introduction

Atyid shrimps (Crustacea: Decapoda) are essential components of tropical freshwater ecosystems, playing a role of cleaner by shredding fallen leaves or filtering organic particular matter and being preys to a number of organisms (Covich *et al.*, 1999 ; Crowl *et al.*, 2001). Among them, genus *Caridina* H. Milne Edwards, 1837 is particularly diversified, comprising more than 300 described species making it the most diversified of the infra-order Caridea (De Grave *et al.*, 2015). In Indo-Pacific Islands, the majority of the species of *Caridina* have an original diadromous lifestyle, with a planktonic marine larval phase and a benthic freshwater adult phase; amphidromy (McDowall, 2007 ; Bauer, 2013). This strategy allows the species to colonize isolated habitats, such as the rivers of volcanic islands, and to survive to the instability of these environments (floods, droughts, volcanism, etc.) by keeping a stock of larvae in the ocean, ready to recolonize depopulated rivers

(Keith *et al.*, 2010). Amphidromy, by isolating populations, has also contributed to establishing the high diversity that exists among caridean shrimps. This diversity, however, is the source of an extreme taxonomic confusion that impedes the monitoring of the species and the establishment of appropriate conservation programs (Klotz & Rintelen, 2014). Recently, with the development of new molecular biology techniques, integrative taxonomy is being increasingly used by systematicians attempting to achieve more precise species delineations by combining morphological data with genetic, ecological and/or biogeographical information (Mazancourt *et al.*, 2017). In this chapter, we 1) review the current state of knowledge of amphidromous *Caridina* diversity in the light of the latest results of integrative taxonomy on this model, 2) review the threats faced by *Caridina* in Indo-Pacific Islands, and 3) discuss how integrative taxonomy approaches can inform and support programs designed to limit the impacts of threatening processes on the diversity of *Caridina*.

11.2 Biodiversity

11.2.1 Taxonomy

There is substantial confusion surrounding the taxonomy of many species of *Caridina* that has resulted in the creation of several species complexes (N.B.: We consider a species complex a monophyletic species group that share a common taxonomic history in having been synonymized at one point, and/or that can be identified by morphological characters). In Indo-Pacific islands, amphidromous shrimps have been grouped into seven main complexes, (1) *Caridina nilotica* (P. Roux, 1833) complex (Johnson, 1963 ; Holthuis, 1978 ; Jaliha *et al.*, 1984 ; Choy, 1991 ; Richard & Clark, 2005 ; Karge & Klotz, 2007), (2) *C. weberi* De Man, 1892 complex (Richard & Chandran, 1994 ; Cai & Shokita, 2006a), (3) *C. gracilirostris* De Man, 1892 complex (Cai & Ng, 2001, 2007), (4) *C. typus* H. Milne Edwards, 1837 complex (Karge & Klotz, 2007 ; Bernardes *et al.*, 2017), (5) *C. serratirostris* De Man, 1892 complex (Cai & Shokita, 2006b), (6) *C. brevicarpalis* De Man, 1892 complex (Short, 2009) and (7) *C. propinqua* De Man, 1908 complex (WK, unpublished). Little work has been done to differentiate among the species clustered within these complexes, possibly due to the difficulty and costs associated with genetic analyses and the highly similar morphology of shrimps from different populations.

To recognize amphidromous species, the egg size is often a good indicator. Small eggs indicate that the species has an indirect development with several planktonic stages that are often marine. Conversely, species with large eggs are most likely landlocked, with a direct development limiting

65 their dispersal abilities, meaning that they are often endemic. However, some species can have
66 small eggs and still be endemic. This can be due to particular conditions that limit the dispersal of
67 marine larvae. For example, oceanic currents or physical barriers (e.g. closed coral lagoons) may
68 prevent dispersal to nearby islands even if larvae are capable of surviving in oceanic conditions. It
69 is not unusual therefore for different types of larval development to occur within one species group.
70 Moreover, in some cases, like in *C. meridionalis* (see Mazancourt *et al.*, 2018) or *C. gracilipes*
71 (WK, unpublished), egg size varies within a single species, depending on the habitat, with generally
72 larger eggs found in upstream localities and smaller eggs near the estuary, suggesting the possibility
73 of facultative amphidromy.

74

75 11.2.2 Phylogeny

76 A recent work (Mazancourt *et al.*, 2019), object of a presentation at the 9th International Crustacean
77 Congress in Washington DC (May 2018), focused on producing a molecular phylogeny of two
78 species complexes from the Indo-Pacific islands, *C. nilotica* and *C. weberi* complexes. This work
79 demonstrated the importance of an integrative taxonomy approach in understanding the diversity of
80 *Caridina*. Non-integrated approaches are likely to underestimate the as the number of species for a
81 locality, with many cryptic/pseudocryptic species confused under a single name, or more rarely,
82 morphotypes of a single variable species described as separate species. As a result, geographical
83 ranges and ecological data concerning poorly delineated species are often misleading, which
84 impedes the establishment of programs that provide sufficient protection and management. The
85 work also found that habitat was often the most important factor leading to the separation of
86 complexes. Species belonging to different complexes live in different habitat types. Identification to
87 species level (or at least species complex level) and monitoring of *Caridina* diversity over time may
88 therefore provide an early warning system that provides information about changes in their
89 environment.

90

91 11.2.3 Habitat

92

93 (Figure 1 here)

94

95 Habitat is a critical factor influencing the distribution of *Caridina* species and it can often be used
 96 as an identification tool to separate species (Mazancourt *et al.*, 2019). *Caridina* shrimps inhabit
 97 different kinds of freshwater ecosystems, divided between lentic environments, such as lakes (n°7
 98 in Fig. 1; Fig. 2L) or swamps (n°8 in Fig. 1; Fig. 2K), and lotic (river) environments for surface
 99 waters, as well as for subterranean waters (n°9 in Fig. 1). Amphidromous shrimps, due to their
 100 ability to migrate between freshwater and seawater are mainly found in rivers or lentic
 101 environments connected to the sea.

102 On the tropical mountainous islands that are typical in the Indo-Pacific, rivers are subject to
 103 important natural disturbances like droughts, floods, volcanic eruptions, or earthquakes. The flow of
 104 rivers can therefore be subject to great temporal variations (strong during floods or zero for
 105 temporary waterways) as well as spatial variations (depending on the slope, substrate type, or plant
 106 cover). The morphology of rivers, for example, plays an important role in determining the
 107 variability of environmental conditions that are often unique to the specific watershed that form
 108 discontinuous units isolated from each other by the sea and geological formations, such as
 109 ridgelines. The length of rivers depends on island morphology, ranging from short streams a few
 110 metres in length to large rivers of several kilometres. Examples of the great diversity of river
 111 lengths in the Indo-Pacific include the Diahot in New Caledonia and the Sigatoka in Fiji.

112 To better characterize the variable environmental conditions experienced by shrimp in different
 113 rivers, Keith *et al.*, (2010) proposed an altitudinal zonation divided into five zones with flexible
 114 boundaries depending on the island studied. The five zones are the spring zone (n°1 in Fig. 1; Fig.
 115 2I), the higher course (n°2 in Fig. 1; Fig. 2A and B), the middle course (n° 4 in Fig. 1; Fig. 2C and
 116 D), the low part of the stream (n°5 in Fig. 1; Fig. 2E and F), and the lower course (n°6 in Fig. 1;
 117 Fig. 2G and H). An additional sub-zonation exists depending on the current velocity, distinguishing
 118 calm zones (Fig. 2C and E) or pools (Fig. 2B) from riffles (Fig. 2A, D and F). Usually, the
 119 altitudinal zonation is further simplified into three functional levels (Fig. 1):

- 120 - The higher course, characterized by a steep slope (generally >10%), a fast current and a boulder
 121 substrate.
- 122 - The middle course, characterized by an intermediate slope (<10%) and a substrate of pebbles and
 123 rocks or sand in calm areas. This level is typically separated from the higher course by a
 124 topographical feature, like a cascade (n°3 in Fig. 1; Fig. 2J).
- 125 - The lower course, characterized by a very low or zero slope, with a slow current and a substrate of
 126 pebbles whose size decreases when approaching the estuary. The estuary is the lowest end of the

127 river where environmental conditions are influenced by the tidal flux of seawater, as distinguished
128 from the purely limnic area. This chemical boundary, between seawater and freshwater, is essential
129 in terms of habitat, for some amphidromous species. The size of the estuary can vary, from very
130 broad and long for large rivers (like the Jordan in Santo, Vanuatu) to absent in some small streams
131 flowing directly from the mountains to the sea.

132 Species living in rivers are subject to a range of biotic and abiotic conditions depending on the zone
133 of the river where they live. Differences in biotic and abiotic conditions often form gradients that
134 apply over the entire length of rivers (Tab. 1):

135 - A current velocity gradient mainly linked to elevation. Water currents are typically fastest at high
136 altitudes and slowest in the estuary, although local variations at a given altitude are also important,
137 depending on the configuration of the river (calm zones vs riffles).

138 - A temperature and oxygen gradient, with cool and oxygen-rich waters typical of the higher course
139 and warm and low-oxygen waters typical of the lower course.

140 - A width and depth gradient, from small rivulets in the spring zone to large rivers near the mouth.

141 - A salinity gradient that is typically limited to the lower course. Salinity tends to decline rapidly
142 outside of the areas influenced by tidal flux.

143 - A sediment size gradient, from bedrock in the spring zone, to boulders and rocks in the higher
144 course, pebbles in the middle course, and sand and silt in the lower course.

145 - A particulate organic matter gradient, with clear, oligotrophic waters in the spring area to turbid,
146 eutrophic waters in the estuary.

147 - A riparian vegetation gradient, with riverbanks consisting of naked rock in the higher course
148 switching to dense riparian vegetation in the lower course.

149 - A predation gradient, with the greatest density and diversity of predatory species (birds, fish)
150 present in the lower course. Predators of shrimp in the higher course are mostly limited to eels
151 (*Anguilla spp.*) or insects (dragonfly larvae, etc.)

152

153 (Table 1 here)

154

155 Gradients in abiotic and biotic factors along rivers overlap in many combinations to create a
156 considerable variety of micro-habitats (Gehrke *et al.*, 2011) to which species of *Caridina* have
157 adapted. We can observe a vertical zonation of species depending on the variation of these factors
158 linked to the elevation, as well as horizontal variables linked to the river configuration, according to
159 the lotic or lentic facies in the area, or micro-habitats (sunken wood, roots, aquatic macrophytes,
160 rocks, etc.). Indeed, different species assemblages are observed at the different levels of the rivers
161 and in the different flowing facies. In the lower course will be encountered species of the *C. nilotica*
162 species complex (Mazancourt *et al.*, 2018), the *C. gracilirostris* species complex or species allied to
163 *C. serratirostris* and *C. brevicarpalis*. Higher in the river, two species groups are found, *C. weberi*
164 complex in lotic areas and *C. nilotica* complex in lentic areas. Species of the *C. typus* group seem to
165 have a broader range of habitats, present virtually in the whole length of the rivers (pers. obs.).

166 As observed for fish in tropical rivers by Pouilly *et al.* (2006) and Lorion *et al.* (2011) in continental
167 systems and by Keith *et al.* (2015) in insular systems, there seems to be an altitudinal diversity
168 gradient in *Caridina*, with a maximum diversity in the lower course, decreasing with elevation. This
169 diversity gradient may be explained by the greater concentration of organic particulate matter in the
170 lower reaches, allowing the establishment of a higher biomass (Angermeier & Karr, 1983).
171 Alternatively, diversification may be promoted by higher heterogeneity in habitats (Gorman &
172 Karr, 1978) and stronger predator pressure in the lower course (Deacon *et al.*, 2018). The proximity
173 to the ocean of the lower course also presents the advantage of reducing the distance that larvae of
174 amphidromous species have to travel to the sea as larvae and to the upper course as juveniles. In
175 higher altitudes, in contrast, resources are more limited but predator pressure is weaker, which often
176 leads to low biodiversity but high abundance (Leberer & Nelson, 2001). Some species living in
177 these environments have adopted a life cycle completed entirely in freshwater, with reduced larval
178 stages or even direct development, avoiding the hazards of migration (Hancock, 1998).

179 It is important to note patterns in diversity across zones can sometimes be more nuanced than the
180 zonation framework proposed by Keith *et al.* (2010) may suggest. In some cases, patterns in
181 diversity can be dominated by a single parameter, such as the nature of the bedrock. In New
182 Caledonia, ultramafic rocks of the South of the island leach high concentrations of metals (nickel,
183 chromium, cobalt) into the water of the rivers. These metals are toxic for most species, but some
184 species that have evolved to tolerate high levels of dissolved metals live there (Marquet *et al.*,
185 2003). These rivers flowing over ultramafic substrate thus exhibit a different fauna than rivers on
186 sedimentary substrate, with different altitudinal zonations.

187

188 (Figure 2 here)

189

190 11.2.4 Biogeography

191 The genus *Caridina* can be found in virtually all the rivers of the tropical Indo-Pacific and Africa,
192 ranging from West Africa (Richard & Clark, 2009), Egypt (Hussein & Obuid-Allah, 1990; Richard
193 & Clark, 2005; Mazancourt *et al.*, in press) and South Africa (Mirimin *et al.*, 2015) to mainland
194 Japan (Saito *et al.*, 2012), Polynesia (Keith *et al.*, 2013) and South Australia (Davie, 2002),
195 stretching to Middle East localities (Christodoulou *et al.*, 2016) (Fig. 3).

196

197 (Figure 3 here)

198

199 As expected for such a wide-ranging genus, regional differences in diversity of *Caridina* exist in the
200 Indo-Pacific. When focusing on endemic species of *Caridina* (Fig. 4A), the maximum diversity
201 occurs around the Coral Triangle (Veron *et al.*, 2009), between the Philippines, Indonesia, and
202 Papua-New Guinea. The number of endemic species tends to be substantially lower in rivers further
203 away from this area, although large continental islands such as Madagascar or Sri Lanka, and
204 archipelagos such as the Solomon Islands, constitute local hotspots of endemism. Some of these
205 hotspots have been exposed by previous studies on freshwater shrimps, including Madagascar (De
206 Grave *et al.*, 2008; De Grave *et al.*, 2015; Cumberlidge *et al.*, 2017) and Sulawesi (De Grave *et al.*,
207 2008; Klotz & Rintelen, 2013; De Grave *et al.*, 2015). Islands of relatively old geological origin
208 like New Caledonia, Fiji, or Mauritius also appear to harbor a high diversity of endemic species. In
209 contrast, younger and often isolated islands like those of Polynesia or Micronesia harbor fewer
210 endemic species. Localities at the northern and southern limits of the distribution area (Japan and
211 South Australia for example) show low endemism.

212

213 (Figure 4 here)

214

215 It appears regional patterns in the diversity in *Caridina* of the Indo-Pacific are explained by the age,
216 size, and latitude of islands. Diversity will likely be high in a large continental island close to the

217 equator and low in a small young volcanic island or in an area away from the equator (Paulay, 1994
218 ; Willig *et al.*, 2003). Geologically old islands have had more opportunity to be colonized by
219 shrimps, and had time for colonizers to adapt and specialize to the different habitats and form new
220 species. Chen & He (2009) showed that the number of speciations in islands, and thus their
221 biodiversity, increases with time, whereas the number of colonizations decreases. According to the
222 same study, the number of endemic species correlates to the size of the island, due to the greater
223 diversity of habitats (geological or climatic differences, for example), which agrees with our
224 observations for large islands such as Madagascar, Sri Lanka, or New Caledonia.

225 The patterns in the diversity of endemic species (Fig. 4C) vary considerably from the patterns in the
226 diversity of amphidromous species (Fig. 4A). The greatest diversity of amphidromous species is
227 found in the Solomon Islands and Vanuatu. This may also include the Coral Triangle, as the
228 diversity of *Caridina* from the area remains poorly known. The high diversity of *Caridina* in this
229 region may be explained by the complex geological history of the area, which lies at the
230 convergence of three tectonic plates. The region contains islands of both continental and volcanic
231 origin, as well as historical connections to Papua in the North.

232 The lowest diversity of amphidromous species is found in Polynesia and at the borders of the
233 distribution area in general (Fig. 4C). Important areas of endemism, such as Madagascar, are not
234 hotspots of diversity for amphidromous species. Localities with low endemism, like the Polynesian
235 or Micronesian islands, often have a higher proportion of amphidromous species.

236 Patterns in the diversity of amphidromous species may be explained by the recent colonization of
237 the islands by amphidromous shrimps with great dispersal abilities, allowing them to colonize these
238 isolated habitats without becoming reproductively isolated. Small islands often exhibit unstable
239 conditions in which endemic landlocked populations could not maintain themselves. In contrast,
240 amphidromous species can repopulate islands following disturbance as they maintain a stock of
241 larvae in the ocean, ready to recolonize depopulated habitats (McDowall, 2007).

242 The landlocked or amphidromous lifestyle of a species is not always linked to it being endemic or
243 widespread, with examples of amphidromous species that are known from a single island for
244 instance. The patterns of diversity of landlocked species are shown in Fig. 4B. Globally, the highest
245 diversity of landlocked species is found in the Coral Triangle with a diminution when one moves
246 away from it, until they completely disappear at the borders of the distribution area of the genus.
247 However, the differences between landlocked and endemic or amphidromous species is that
248 landlocked species are mainly absent from volcanic islands such as Polynesia, Micronesia, Solomon

Islands, or Vanuatu, where the majority of species are amphidromous. In contrast landlocked species often constitute the majority of the species in continents (India, China, Australia, South Africa) or large continental islands (Madagascar). This supposes that habitats for landlocked species need to have been available for sufficient time for new species to evolve a landlocked lifestyle from amphidromous ancestors, or for species to diverge from landlocked ancestors that were already present.

255

11.3 Conservation

Taxonomic confusion was until now a substantial obstacle to the establishment of programs aimed at the conservation of species of *Caridina*. Some ill-delineated species like *C. longirostris* or *C. weberi* were thought to be widespread, however, studies using an integrative taxonomy approach (Mazancourt *et al.*, 2018) showed that these ‘species’ are actually comprised of several species with more restricted distributions (some even being endemic). Furthermore, a better knowledge of systematics allows greater understanding of the habitat and ecology of these species, since each species is adapted to a different environment. These new data will impact the way in which the conservation status of these species is assessed. Species with small distributions and specific habitat needs are more vulnerable to extinction than widespread and tolerant species (Purvis *et al.*, 2000).

266

11.3.1 Threats to amphidromous *Caridina*

The main threats faced by *Caridina* almost always originate from anthropization of their environment.

Habitat degradation. Many anthropic activities induce habitat degradation. The direct impacts of habitat degradation occur through impact through pollution of the rivers by pesticides (Kumar *et al.*, 2010a ; Kumar *et al.*, 2010b), industrial accidents (Dominique, 2014), illegal poisoning (Greathouse *et al.*, 2005), use of the rivers as dumps (Keith *et al.*, 2006), eutrophication by fertilizers, poisoning and causing the proliferation of algae clogging the rivers, or increased sedimentation from mining, gravel extraction, or constructions (dams, roads, etc.) smothering the stream bed, and increasing water turbidity (Boseto *et al.*, 2007; Keith *et al.*, 2013). Habitat destruction also occurs through the removal of water from river systems for agriculture, industry or tourism, causing physical changes (e.g. lower flow rates) and the disappearance of lotic zones (Keith *et al.*, 2013) that are the exclusive habitat of some species (e.g. *Caridina weberi* species complex). The cause and effects of

280 habitat destruction can also be associated with human activities that do not impact rivers directly
281 but have flow-on effects that impact shrimp habitats and threaten the viability of populations (i.e.
282 indirect effects). For example, the disappearance of perennial rivers and associated loss of habitat
283 for shrimp due to deforestation, like in Rodrigues Island (Keith *et al.*, 2006), in Madagascar for
284 rosewood, in Anjouan (Mirhani *et al.*, 2014) for firewood and Ylang-ylang plantations, in the
285 Marquesas islands and Rapa for goats and livestock, or in New Caledonia due to bushfires. As some
286 species of amphidromous shrimps live in mangroves (like those of the *C. gracilirostris* complex),
287 they are threatened during both their larval and adult stages by the degradation of their habitat by
288 aquaculture activities. Together, the impacts of aquatic and terrestrial habitat destruction are well
289 documented to affect the physiology, reproduction and migration of caridean shrimp and remain
290 one of the most important threatening processes for carideans and other freshwater species (De
291 Grave *et al.* 2015).

292 *Reduced connectivity.* The construction of instream barriers suppresses habitat connectivity
293 (Dudgeon, 2000 ; March *et al.*, 2003). The construction of dams, such as the Yaté hydroelectric
294 plant in New Caledonia, are one such example of instream barriers that result in a rapid
295 disappearance of amphidromous species in the whole watershed upstream. Indeed, shrimps need to
296 be able to migrate along the river course depending on the water level in order to not get trapped in
297 pools during the dry season. For amphidromous species, it is critical to have a continuum between
298 the adult habitat and the sea in order to maintain populations.

299 *Introduced species.* The introduction of exotic species can lead to local extinctions of indigenous
300 species due to predation, competition, habitat alteration, or disease transmission (Keith, 2002a,
301 2002b; De Grave *et al.*, 2015). For caridean shrimp, another important but little studied threat
302 associated with introduced species, is the potential for hybridization with non-native caridean
303 species. The ease with which caridean shrimp hybridize is well noted in the aquarium literature.
304 There have been no reports of hybridization of introduced and native carideans in the wild, but the
305 extinction of local populations due to hybridization following a translocation within a catchment
306 has already occurred in other genera within the family Atyidae (Hughes *et al.*, 2003; Fawcett *et al.*,
307 2010).

308 *Overharvesting.* Shrimps are harvested for human consumption. In the Philippines, Madagascar,
309 Indonesia, India, and China, caridean shrimp are caught using nets in large quantities to be eaten
310 fresh, dried, or salted, and to feed animals or used as fertilizer (Holthuis, 1980), or in Reunion
311 Island where they are called “chevaquines” (GM, pers. comm.). A unique threat for *Caridina* spp. is
312 the capture of individuals for the aquarium trade, particularly for the colorful species living in

313 Sulawesi (De Grave *et al.*, 2015) or “Bee shrimps” from mainland China, some species being
314 known only from a single stream of about 150m in length (WK pers. comm.). While most of the
315 species impacted are lacustrine landlocked, in the future growing global demand could see the
316 expansion of the collection of amphidromous species. Currently, only a few amphidromous species
317 appear in the trade, but whether these are collected legally, poached, or bred in captivity is difficult
318 to determine due to long and complex supply chains. It is unclear how many shrimp are traded
319 globally, but there is substantial anecdotal evidence suggesting local populations experience severe
320 declines due over-collection, particularly where a local colour or pattern variant becomes highly
321 sort after in the trade. For example, Klotz & Lukhaup (2014) reported the disappearance of
322 *Caridina trifascata* from locales near Zuhai, China over a period of less than 12 months, likely
323 associated with over-harvesting for the aquarium trade.

324 *Climate change.* Climate change is likely already impacting and will continue to impact caridean
325 shrimp through a variety of direct and indirect mechanisms (Table 1). Unfortunately, whilst
326 crustaceans generally appear to be robust to some changes in their environment associated with
327 climate change (e.g. ocean acidification), little research has been done to address the gaps in our
328 knowledge about indirect effects of climate stressors, and the effects of interactions of climate
329 stressors (e.g. temperature) with non-climate stressors (e.g. pesticide pollution). This is concerning
330 given studies that have examined the indirect and interactive effects of climate stressors on marine
331 taxa have highlighted how these effects may be more important than the direct effects of climate
332 stressors (e.g. Kanya *et al.*, 2017; Rosenblatt & Schmitz, 2016; Kroeker *et al.*, 2012; Boyd &
333 Brown, 2015).

334
335 (Table 2 here)

336

337 11.3.2 Conclusions and recommendations

338 The integrative study of *Caridina* led to the discovery of unsuspected diversity in Indo-Pacific
339 Islands, with species complexes that are now recognized and present differences in habitat.
340 Therefore, when making inventories of the freshwater fauna of rivers, if it is not possible to identify
341 specimens to species level, the species complex can be sufficient to provide interesting data. Keys
342 and diagnoses of the different species complexes will be presented in an upcoming study
343 (Mazancourt *et al.* submitted). Now that species are better delineated thanks to integrative

344 taxonomy, their distribution (including micro and macro-habitats) can be more informative and
345 their specific conservation status (threats, IUCN status, etc.) needs to be re-assessed.

346 Our recommendations to protect these amphidromous species of *Caridina* revolve around three
347 main points:

348 1) Taking biological and ecological specificities into consideration

349 Arguably the best way to enable conservation is by changing the mind-set of people directly
350 implicated through education and example. For example, managing caridean species requires
351 managers to have a minimum knowledge of their biology (i.e. amphidromous lifecycle) and to
352 take their specificities into consideration when making decisions. Understanding of the
353 lifecycles of amphidromous species highlights the importance of maintaining the natural flow of
354 water ways in a good state. Maintaining population connectivity through natural water flows
355 allows populations to be comprised of a range of life stages. This limits the potential for local or
356 regional extinctions as breeding populations depend on the pool of larvae to replace them (and
357 conversely, the pool of larvae depends on the breeding populations). Successful implementation
358 of conservation measures designed to maintain and enhance natural water flows may be best
359 achieved through the inclusion of a range of stakeholders in projects (e.g. farmers, fishers, water
360 management authorities, local government, community conservation groups, international
361 conservation organisations, etc.).

362

363 2) Limiting anthropic impacts on amphidromous species

364 The most efficient way to protect amphidromous species is to protect their environment by
365 limiting anthropic impacts. This requires an integrated management approach that takes into
366 account the role of both terrestrial and aquatic impacts. For example, water catchments should
367 always have a minimum flow in line with their natural seasonal variations, considering the
368 upstream migration of the juveniles is often triggered by greater freshwater arrival in the sea
369 during floods. Therefore the effects of a variety of management decisions, such as avoiding
370 man-made structures altering water flow, design of roads and dams that maintain the
371 connectivity from the sea to the mountains, maintaining riparian vegetation in a good state, and
372 preserving estuarine habitats, need to be considered in an integrated manner.

373

2) Establishing priorities for species conservation

As conservation status is not known for many species, the priority is to protect their habitats. It would thus be useful to identify those habitats that need special protection and make sure to apply to them the recommendations of the previous point. Caridean shrimps seem to be good indicators of water and habitat quality. They could thus be a very useful tool for managers as indicators of anthropic effects and the impact of climate change in tropical rivers. As exotic species are often harmful to native fauna, preventing their introduction would be an important recommendation to preserve freshwater shrimps. Finally, supporting research on the biology and ecology of these species would help to improve our knowledge and assess the threats they face.

References

- Angermeier, P. L. & Karr, J. R. (1983) Fish communities along environmental gradients in a system of tropical streams. *Environmental Biology of Fishes*, 9(2): 117-135.
- Bauer, R. T. (2013) Amphidromy in shrimps: a life cycle between rivers and the sea. *Latin American Journal of Aquatic Research*, 41(4): 633-650.
- Beaugrand, G. & Kirby, R. R. (2018) How do marine pelagic species respond to climate change? Theories and observations. *Annual Review of Marine Science*, 10: 169-197.
- Bernardes, S. C., Pepato, A. R., Rintelen (von), T., Rintelen (von), K., Page, T. J., Freitag, H. & de Bruyn, M. (2017) The complex evolutionary history and phylogeography of *Caridina typus* (Crustacea: Decapoda): long-distance dispersal and cryptic allopatric species. *Scientific Reports*, 7(1): 9044.
- Boseto, D., Morrison, C., Pikacha, P. & Pitakia, T. (2007) Biodiversity and conservation of freshwater fishes in selected rivers on Choiseul Island, Solomon Islands. *The South Pacific Journal of Natural Science*, 3(1): 16-21.
- Boyd, P. W. & Brown, C. J. (2015) Modes of interactions between environmental drivers and marine biota. *Frontiers in Marine Sciences*, 2(9): 1-7.
- Breitburg, D., Levin, L. A., Oschlies, A., Grégoire, M., Chavez, F. P., Conley, D. J., Garçon, V., Gilbert, D., Gutiérrez, D., Isensee, K., Jacinto, G. S., Limburg, K. E., Montes, I., Naqvi, S. W. A., Pitcher, G. C., Rabalais, N. N., Roman, M. R., Rose, K. A., Seibel, B. A.,

- 405 Telszewski, M., Yasuhara, M. & Zhang, J. (2018) Declining oxygen in the global ocean and
406 coastal waters. *Science*, 359(6371): eaam7240.
- 407 Cai, W., Wang, G., Dewitte, B., Wu, L., Santoso, A., Takahashi, K., Yang, Y., Carréric, A. &
408 McPhaden, M. J. (2018) Increased variability of eastern Pacific El Niño under greenhouse
409 warming. *Nature*, 564(7735): 201-206.
- 410 Cai, Y. & Ng, P. K. L. (2001) The freshwater decapod crustaceans of Halmahera, Indonesia.
411 *Journal of Crustacean Biology*, 21(3): 665-695.
- 412 Cai, Y. & Ng, P. K. L. (2007) A revision of the *Caridina gracilirostris* De Man, 1892, species
413 group, with descriptions of two new taxa (Decapoda; Caridea; Atyidae). *Journal of Natural*
414 *History*, 41((25-28)): 1585-1602.
- 415 Cai, Y. & Shokita, S. (2006a) Atyid shrimps (Crustacea: Decapoda: Caridea) of the Ryukyu Islands,
416 southern Japan, with descriptions of two new species. *Journal of Natural History*, 40(38-
417 40): 2123-2172.
- 418 Cai, Y. & Shokita, S. (2006b) Report on a collection of freshwater shrimps (Crustacea: Decapoda:
419 Caridea) from the Philippines, with descriptions of four new species. *The Raffles Bulletin of*
420 *Zoology*, 54(2): 245-270.
- 421 Chen, X.-Y. & He, F. (2009) Speciation and endemism under the model of island biogeography.
422 *Ecology*, 90(1): 39-45.
- 423 Choy, S. C. (1991) The atyid shrimps of Fiji with description of a new species. *Zoologische*
424 *Mededelingen*, 65(27): 343-362.
- 425 Christodoulou, M., Anastasiadou, C., Jugovic, J. & Tzomos, T. (2016) Freshwater Shrimps
426 (Atyidae, Palaemonidae, Typhlocarididae) in the Broader Mediterranean Region:
427 Distribution, Life Strategies, Threats, Conservation Challenges and Taxonomic Issues. In:
428 T. Kawai & N. Cumberlidge (Eds), *A Global Overview of the Conservation of Freshwater*
429 *Decapod Crustaceans*. Springer, Cham, pp. 199-236.
- 430 Comte, L. & Grenouillet, G. (2013) Do stream fish track climate change? Assessing distribution
431 shifts in recent decades. *Ecography*, 36: 1236-1246.
- 432 Covich, A. P., Palmer, M. A. & Crowl, T. A. (1999) The role of benthic invertebrate species in
433 freshwater ecosystems. *BioScience*, 49: 119-128.
- 434 Crowl, T. A., McDowell, W. H., Covich, A. P. & Johnson, S. L. (2001) Freshwater shrimp effects
435 on detrital processing and nutrients in a tropical headwater stream. *Ecology*, 82(3): 775-783.
- 436 Cumberlidge, N., Rasamy Razanabolana, J., Ranaivoson, C. H., Randrianasolo, H. H., Sayer, C.,
437 Máiz-Tomé, L., Van Damme, D. & Darwall, W. R. T. (2017) Updated extinction risk

438 assessments of Madagascar's freshwater decapod crustaceans reveal fewer threatened
 439 species but more Data Deficient species. *Malagasy Nature*, 12: 32-41.

440 Davie, P. J. F. (2002) Crustacea: Malacostraca: Phyllocarida, Hoplocarida, Eucarida (Part 1). In: A.
 441 Wells & W. W. K. Houston (Eds), *Zoological Catalogue of Australia*. CSIRO Publishing,
 442 Australia, Melbourne, p. 551.

443 De Grave, S., Cai, Y. & Anker, A. (2008) Global diversity of shrimps (Crustacea: Decapoda:
 444 Caridea) in freshwater. *Freshwater Animal Diversity Assessment*, 595: 287-293.

445 De Grave, S., Smith, K. G., Adeler, N. A., Allen, D. J., Alvarez, F., Anker, A., et al. (2015) Dead
 446 Shrimp Blues: A Global Assessment of Extinction Risk in Freshwater Shrimps (Crustacea:
 447 Decapoda: Caridea). *PLoS ONE*, 10(3): e0120198.

448 Deacon, A. E., Jones, F. A. M. & Magurran, A. E. (2018) Gradients in predation risk in a tropical
 449 river system. *Current Zoology*, 64(2): 213-221.

450 Dominique, Y. (2014) Constat de pollution suite à un déversement d'effluent industriel au sein du
 451 creek de la Baie Nord. In: Oeil, Nouméa, New Caledonia, pp. 1-35.

452 Dudgeon, D. (2000) Large-Scale Hydrological Changes in Tropical Asia: Prospects for Riverine
 453 Biodiversity: The construction of large dams will have an impact on the biodiversity of
 454 tropical Asian rivers and their associated wetlands. *BioScience*, 50(9): 793-806.

455 Fawcett, J. H., Hurwood, D. A. & Hughes, J. M. (2010) Consequences of a translocation between
 456 two divergent lineages of the *Paratya australiensis* (Decapoda: Atyidae) complex:
 457 reproductive success and relative fitness. *Journal of the North American Benthological*
 458 *Society*, 29(3): 1170-1180.

459 Ficke, A. D., Myrick, C. A. & Hansen, L. J. (2007) Potential impacts of global climate change on
 460 freshwater fisheries. *Reviews in Fish Biology and Fisheries*, 17(4): 581-613.

461 Gehrke, P. C., Sheaves, M. J., Boseto, D. T., Figa, B. S. & Wani, J. (2011) Chapter 7: Vulnerability
 462 of freshwater and estuarine fish habitats in the tropical Pacific to climate change. In: J. D.
 463 Bell, J. E. Johnson & A. J. Hobday (Eds), *Vulnerability of tropical Pacific fisheries and*
 464 *aquaculture to climate change*. Secretariat of the Pacific Community, Auckland, New
 465 Zealand, pp. 369-431.

466 Gorman, O. T. & Karr, J. R. (1978) Habitat Structure and Stream Fish Communities. *Ecology*,
 467 59(3): 507-515.

468 Greathouse, E. A., March, J. G. & Pringle, C. M. (2005) Recovery of a tropical stream after a
 469 harvest-related chlorine poisoning event. *Freshwater Biology*, 50(4): 603-615.

- 470 Hancock, M. A. (1998) The relationship between egg size and embryonic and larval development in
471 the freshwater shrimp *Paratya australiensis* Kemp (Decapoda: Atyidae). *Freshwater*
472 *Biology*, 39(4): 715-723.
- 473 Hays, G. C., Richardson, A. J. & Robinson, C. (2005) Climate change and marine plankton. *Trends*
474 *in Ecology and Evolution*, 20: 337-344.
- 475 Holthuis, L. B. (1978) A collection of Decapod Crustacea from Sumba, Lesser Sunda islands,
476 Indonesia. *Zoologische Verhandelingen*, 162: 1-55.
- 477 Holthuis, L. B. (1980) *FAO species catalogue. Volume 1-Shrimps and prawns of the world* (An
478 annotated catalogue of species of interest to fisheries Vol. 1). Food and Agriculture
479 Organization of the United Nations, Rome, Italy (271p).
- 480 Hughes, J. M., Goudkamp, K., Hurwood, D. A., Hancock, M. A. & Bunn, S. (2003) Translocation
481 causes extinction of a local population of the freshwater shrimp *Paratya australiensis*.
482 *Conservation Biology*, 17(4): 1007-1012.
- 483 Hussein, M. A. & Obuid-Allah, A. H. (1990) External morphology of the freshwater prawn
484 *Caridina africana* collected from Egypt. *Zoology in the Middle East*, 4(1): 71-84.
- 485 Jackson, M. C., Loewen, C. J., Vinebrooke, R. D. & Chimimba, C. T. (2016) Net effects of multiple
486 stressors in freshwater ecosystems: a meta-analysis. *Global Change Biology*, 22(1): 180-
487 189.
- 488 Jaliha, D. R., Shenoy, S. & Sankolli, K. N. (1984) Five new species of freshwater atyid shrimps of
489 the genus *Caridina* H. Milne Edwards from Dharwar area (Karnataka State, India). *Records*
490 *of the Zoological Survey of India. Miscellaneous Publication, Occasional Paper*, 69: 1-40.
- 491 Johnson, D. S. (1963) Distributional and other notes on some freshwater prawns (Atyidae and
492 Palaemonidae) mainly from the Indo-West Pacific region. *Bulletin of the National Museum*
493 *of Singapore*, 32: 5-30.
- 494 Kamya, P. Z., Byrne, M., Mos, B., Hall, L. & Dworjanyn, S. A. (2017) Indirect effects of ocean
495 acidification drive feeding and growth of juvenile crown-of-thorns starfish *Acanthaster*
496 *planci*. *Proceedings of the Royal Society of London Series B: Biological Sciences*,
497 284(1856): 20170778.
- 498 Karge, A. & Klotz, W. (2007) *Süßwassergarnelen aus aller Welt*. Dähne Verlag (198p).
- 499 Keith, P. (2002a) Freshwater fish and decapod crustacean populations on Reunion Island, with an
500 assessment of species introductions. *Bulletin Français de la Pêche et de la Pisciculture*,
501 364: 97-107.
- 502 Keith, P. (2002b) Introduction of freshwater fishes and decapod crustaceans in French Polynesia, a
503 review. *Bulletin Français de la Pêche et de la Pisciculture*, 364: 147-160.

Keith, P., Lord, C. & Maeda, K. (2015) *Indo-Pacific Sicydiine Gobies: biodiversity, life traits and conservation*. Société Française d'Ichtyologie, Paris (256p).

Keith, P., Marquet, G., Gerbeaux, P., Vigneux, E. & Lord, C. (2013) *Poissons et crustacés d'eau douce de Polynésie*. Société Française d'Ichtyologie, Paris (282p).

Keith, P., Marquet, G., Lord, C., Kalfatak, D. & Vigneux, E. (2010) *Vanuatu freshwater fish and crustaceans*. Société Française d'Ichtyologie, Paris (254p).

Keith, P., Marquet, G., Valade, P., Bosc, P. & Vigneux, E. (2006) *Atlas des poissons et des crustacés d'eau douce des Comores, Mascareignes et Seychelles* (Collection Patrimoines naturels Vol. 65). MNHN, Paris, France (250p).

Klotz, W. & Lukhaup, C. (2014) *Breeders'n'Keepers Wildshrimp China Special*. Dennerle GmbH, Vinningen, Germany (122p).

Klotz, W. & Rintelen (von), K. (2013) Three new species of *Caridina* (Decapoda: Atyidae) from Central Sulawesi and Buton Island, Indonesia, and a checklist of the islands' endemic species. *Zootaxa*, 3664(4): 554-570.

Klotz, W. & Rintelen (von), T. (2014) To "bee" or not to be - on some ornamental shrimp from Guangdong Province, Southern China and Hong Kong SAR, with descriptions of three new species. *Zootaxa*, 3889(2): 151-184.

Kroeker, K. J., Kordas, R. L., Crim, R., Hendriks, I. E., Ramajo, L., Singh, G. S., Duarte, C. M. & Gattuso, J.-P. (2013) Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. *Global Change Biology*, 19(6): 1884-1896.

Kroeker, K. J., Micheli, F. & Gambi, M. C. (2012) Ocean acidification causes ecosystem shifts via altered competitive interactions. *Nature Climate Change*, 3: 156-159.

Kumar, A., Doan, H., Barnes, M., Chapman, J. C. & Kookana, R. S. (2010a) Response and recovery of acetylcholinesterase activity in freshwater shrimp, *Paratya australiensis* (Decapoda: Atyidae) exposed to selected anti-cholinesterase insecticides. *Ecotoxicology and Environmental Safety*, 73(7): 1503-1510.

Kumar, A., R., C., Grocke, S. & Bajet, C. (2010b) Toxicity of selected pesticides to freshwater shrimp, *Paratya australiensis* (Decapoda: Atyidae): Use of time series acute toxicity data to predict chronic lethality. *Ecotoxicology and Environmental Safety*, 73(3): 360-369.

Leberer, T. & Nelson, S. G. (2001) Factors affecting the distribution of atyid shrimps in two tropical insular rivers. *Pacific Science*, 55: 389-398.

Lorion, C. M., Kennedy, B. P. & Braatne, J. H. (2011) Altitudinal gradients in stream fish diversity and the prevalence of diadromy in the Sixaola River basin, Costa Rica. *Environmental Biology of Fishes*, 91(4): 487-499.

- 538 Lough, J. M., Meehl, G. A. & Salinger, M. J. (2011) Chapter 2: Observed and projected changes in
539 surface climate of the tropical Pacific. *In*: J. D. Bell, J. E. Johnson & A. J. Hobday (Eds),
540 *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*. Secretariat
541 of the Pacific Community, Auckland, New Zealand, pp. 49-99.
- 542 March, J. G., Benstead, J. P., Pringle, C. M. & Scatena, F. N. (2003) Damming Tropical Islands
543 Streams: Problems, Solutions and Alternatives. *BioScience*, 53(11): 1069-1078.
- 544 Marquet, G., Keith, P. & Vigneux, E. (2003) *Atlas des poissons et des crustacés d'eau douce de*
545 *Nouvelle-Calédonie* (Collection Patrimoines naturels Vol. 58). MNHN, Paris, France
546 (288p).
- 547 Mazancourt (de), V., Klotz, W., Marquet, G. & Keith, P. (2018) Integrative taxonomy helps
548 separate four species of freshwater shrimps commonly overlooked as *Caridina longirostris*
549 (Crustacea: Decapoda: Atyidae) in Indo-West Pacific islands. *Invertebrate Systematics*,
550 32(6): 1422-1447.
- 551 Mazancourt (de), V., Klotz, W., Marquet, G., Mos, B., Rogers, D. C. & Keith, P. (2019) The
552 complex study of complexes: The first well-supported phylogeny of two species complexes
553 within genus *Caridina* (Decapoda: Caridea: Atyidae) sheds light on evolution,
554 biogeography, and habitat. *Molecular Phylogenetics and Evolution*, 131: 164-180.
- 555 Mazancourt (de), V., Marquet, G., Klotz, W., Keith, P. & Castelin, M. (2017) When morphology
556 and molecules work together: lines of evidence for the validity of *Caridina buehleri* Roux,
557 1934 (Crustacea: Decapoda: Atyidae) and *Caridina gueryi* Marquet, Keith & Kalfatak, 2009
558 as its junior synonym. *Invertebrate Systematics*, 31: 220-230.
- 559 McDowall, R. (2007) On amphidromy, a distinct form of diadromy in aquatic organisms. *Fish and*
560 *Fisheries*, 8(1): 1-13.
- 561 Mcleod, E., Poulter, B., Hinkel, J., Reyes, E. & Salm, R. (2010) Sea-level rise impact models and
562 environmental conservation: A review of models and their applications. *Ocean & Coastal*
563 *Management*, 53(9): 507-517.
- 564 Mirhani, N., Taïbi, A. N., Ballouche, A. & Razakamanana, T. (2014) De la problématique de l'eau
565 au modèle numérique d'aménagement en milieu tropical humide insulaire : le bassin versant
566 d'Ouzini-Ajaho (Anjouan – Comores). *In*: A. Ballouche (Ed), *Eau, milieux et aménagement.*
567 *Une recherche au service des territoires*. Presses Universitaires d'Angers, pp. 117-134.
- 568 Mirimin, L., Kitchin, N., Impson, D. N., Clark, P. F., Richard, J., Daniels, S. R. & Roodt-Wilding,
569 R. (2015) Genetic and morphological characterization of freshwater shrimps (*Caridina*
570 *africana* Kingsley, 1882) reveals the presence of alien shrimps in the Cape Floristic Region,
571 South Africa. *Journal of Heredity*, 106(6): 711-718.

- 572 Mos, B., Ah Yong, S. T., Burnes, C. N., Davie, P. J. F. & McCormack, R. B. (2017) Range extension
573 of a euryhaline crab, *Varuna litterata* (Fabricius, 1798) (Brachyura: Varunidae), in a climate
574 change hot-spot. *Journal of Crustacean Biology*, 37: 258-262.
- 575 Paulay, G. (1994) Biodiversity on Oceanic Islands: Its Origin and Extinction. *American Zoologist*,
576 34(1): 134-144.
- 577 Pecl, G. T., Araújo, M. B., Bell, J. D., Blanchard, J., Bonebrake, T. C., Chen, I.-C., Clark, T. D.,
578 Colwell, R. K., Danielsen, F., Evengard, B., Falconi, L., Ferrier, S., Frusher, S., Garcia, R.
579 A., Griffis, R. B., Hobday, A. J., Janion-Scheepers, C., Jarzyna, M. A., Jennings, S., Lenoir,
580 J., Linnetved, H. I., Martin, V. Y., McCormack, P. C., McDonald, J., Mitchell, N. J.,
581 Mustonen, T., Pandolfi, J. M., Pettorelli, N., Popova, E., Robinson, S. A., Scheffers, B. R.,
582 Shaw, J. D., Sorte, C. J. B., Strugnell, J. M., Sunday, J. M., Tuanmu, M.-N., Vergés, A.,
583 Villanueva, C., Wernberg, T., Wapstra, E. & Williams, S. E. (2017) Biodiversity
584 redistribution under climate change: Impacts on ecosystems and human well-being. *Science*,
585 355.
- 586 Pouilly, M., Barrera, S. & Rosales, C. (2006) Changes of taxonomic structure of fish assemblages
587 along an environmental gradient in the Upper Beni watershed (Bolivia). *Journal of Fish*
588 *Biology*, 68(1): 137-156.
- 589 Purvis, A., Gittleman, J. L., Cowlishaw, G. & Mace, G. M. (2000) Predicting extinction risk in
590 declining species. *Proceedings of the Royal Society of London Series B: Biological*
591 *Sciences*, 267(1456): 1947-1952.
- 592 Rastetter, E. B., McKane, R. B., Shaver, G. R. & Melillo, J. M. (1992) Changes in C storage by
593 terrestrial ecosystems: How CN interactions restrict responses to CO₂ and temperature. *In*:
594 *Natural Sinks of CO₂*. Springer, Dordrecht, pp. 327-344.
- 595 Richard, J. & Chandran, M. R. (1994) A systematic report on the fresh water prawns of the atyid
596 genus *Caridina* H. Milne Edwards 1837, from Madras (Tamilnadu: India). *Journal of the*
597 *Bombay Natural History Society*, 91: 241-259.
- 598 Richard, J. & Clark, P. F. (2005) *Caridina nilotica* (P. Roux, 1833) (Crustacea: Decapoda: Caridea:
599 Atyidae) from East Africa, with descriptions of four new species. *Proceedings of the*
600 *Biological Society of Washington*, 118(4): 706-730.
- 601 Richard, J. & Clark, P. F. (2009) African *Caridina* (Crustacea: Decapoda: Caridea: Atyidae):
602 redescrptions of *C. africana* Kingsley, 1882, *C. togoensis* Hilgendorf, 1893, *C. natalensis*
603 Bouvier, 1925 and *C. roubaudi* Bouvier, 1925 with descriptions of 14 new species. *Zootaxa*,
604 1995: 1-75.

- 605 Rosenblatt, A. E. & Schmitz, O. J. (2016) Climate change, nutrition and bottom-up and top-down
606 food web processes. *Trends in Ecology and Evolution*, 31(12): 965-975.
- 607 Saito, M., Yamashiro, T., Hamano, T. & Nakata, K. (2012) Factors affecting distribution of
608 freshwater shrimps and prawns in the Hiwasa River, southern Japan. *Crustacean Research*,
609 41: 27-46.
- 610 Short, J. W. (2009) *Freshwater Crustacea of the Mimika Region, New Guinea*. PT Freeport
611 Indonesia, Kuala Kencana, Timika (96p).
- 612 Staudt, A., Leidner, A. K., Howard, J., Brauman, K. A., Dukes, J. S., Hansen, L. J., Paukert, C.,
613 Sabo, J. & Solorzano, L. A. (2013) The added complications of climate change:
614 understanding and managing biodiversity and ecosystems. *Frontiers in Ecology and the*
615 *Environment*, 11(9): 494-501.
- 616 Sterner, R. S. & Elser, J. J. (2002) *Ecological stoichiometry: the biology of elements from molecules*
617 *to the biosphere*. Princeton University Press, Princeton (NJ), USA.
- 618 Vaquer-Sunyer, R. & Duarte, C. M. (2008) Thresholds of hypoxia for marine biodiversity.
619 *Proceeding of the National Academy of Sciences*, 105(40): 15452-15457.
- 620 Veron, J. E. N., Devantier, L. M., Turak, E., Green, A. L., Kininmonth, S., Stafford-Smith, M. &
621 Peterson, N. (2009) Delineating the Coral Triangle. *Galaxea, Journal of Coral Reef Studies*,
622 11(2): 91-100.
- 623 Willig, M. R., Kaufman, D. M. & Stevens, R. D. (2003) Latitudinal gradients of biodiversity:
624 Pattern, Process, Scale, and Synthesis. *Annual Review of Ecology, Evolution, and*
625 *Systematics*, 34(1): 273-309.
- 626 Wittmann, A. C. & Pörtner, H. O. (2013) Sensitivities of extant animal taxa to ocean acidification.
627 *Nature Climate Change*, 3(11): 995.

630 **Figures captions:**

631 **Figure 1.** Schematic representation of the different freshwater habitats. 1: Spring zone; 2: Higher
632 course; 3: Waterfall; 4: Middle course; 5: Lower course; 6: Estuary; 7: Lake; 8: Swamp; 9:
633 Subterranean waters.

634 **Figure 2.** Examples of habitats types. A: Higher course riffle, lotic mode (River Poitete,
635 Kolombangara Island, Solomon Islands, credit PK); B: Higher course pool, lentic mode (Ciu
636 waterfall, New Caledonia, credit VM); C: Middle course, lentic mode (River Wénou, New
637 Caledonia, credit VM); D: Middle course riffle, lotic mode (River Nekouri, New Caledonia, credit

638 VM); E: Lower course, lentic mode (River Hienghène, New Caledonia, credit VM); F: Lower
639 course riffle, lotic mode (River Negropo, New Caledonia, credit VM); G: Mangrove estuary (River
640 Tanghène, New Caledonia, credit VM); H: Estuary, low tide (Nera estuary, New Caledonia, credit
641 VM); I: Mountain stream (Unnamed tributary of the river Ciit, New Caledonia, credit VM); J:
642 Waterfall (Colnett waterfall, New Caledonia, credit VM); K: Swamp (Plaine des Lacs, New
643 Caledonia, credit VM); L: Lake (Lac en Huit, New Caledonia, credit VM).

644 **Figure 3.** Distribution area of *Caridina*.

645 **Figure 4.** Heat maps representing the species richness by locality. A: numbers of amphidromous
646 species (eggs < 0.8mm); B: numbers of landlocked species (eggs > 0.8mm); C: numbers of endemic
647 species (known from a single locality/area).