Freshwater Fishes & Crustaceans of the Mt. Panié and Roches de la Ouaième Watersheds, New Caledonia

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Chapter 4

Freshwater fishes & crustaceans of the Mt. Panié and Roches de la Ouaième watersheds, New Caledonia

Inventaire des poissons et des crustacés d'eau douce du massif du Panié et des Roches de la Ouaième, Nouvelle-Calédonie

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SUMMARY

The freshwater fauna of New Caledonia is rich and consists of 101 described species (64 fish and 37 decapoda crustaceans). Among these species, 25 are endemic to New Caledonia ; Mt. Panié holds many of them and is therefore a priority area for new-caledonian freshwater conservation. Fish and crustaceans of this area were investigated during a rapid assessment survey (RAP) from 10/10/2010 to 21/10/2010 at three sites: La Guen (4 stations), Wewec (5 stations) and Roches de la Ouaième (1 station). We collected ten species of crustaceans and 9 species of fish, all of which are diadromous amphidromous. Only one species was introduced. Considering the number of species found, crustaceans are more diverse in La Guen than in Wewec and on the contrary, fish are more diverse in Wewec than in La Guen. Roches de la Ouaième is the poorest site in terms of fish and crustacean richness. The RAP sites do not have high species richness compared with those from nearby coastal rivers on the eastern side of Mt. Panié.

As all fish and crustacean species caught are diadromous, they are highly sensitive to human impacts on aquatic habitats, particularly in estuarine habitats. These species have to undertake two migrations between freshwater and the sea. The success of such a life cycle - *i.e.* production of larvae for downstream migration after hatching and restocking rivers with post-larval and juvenile upstream colonisation after recruitment in freshwater – depends on maintaining the mountain-ocean corridor to allow movements between both habitats.

RESUME

La riche faune d'eau douce de Nouvelle-Calédonie comprend 101 espèces (64 poissons et crustacés décapodes 37). Parmi ces espèces, 25 sont endémiques et la région du Mont Panié, l'un des sites prioritaires pour la conservation du groupe taxonomique en Nouvelle-Caledonie. Poissons et crustacés de cette région ont été étudiés du 10 au 21 octobre 2010 sur trois sites: La Guen (4 stations), Wewec (5 stations) et Roches de la Ouaième (1 station). Dix espèces de crustacés et 9 espèces de poissons ont été inventoriées ; elles sont principalement diadromes. Une seule espèce introduite a été trouvée. Les crustacés sont plus diversifiés dans La Guen que dans la Wewec et, au contraire, les poissons sont plus diversifiés dans la Wewec que dans La Guen. Le site des Roches de la Ouaième est le plus pauvre en termes de richesse spécifique en poissons et crustacés. Globalement ces sites sont moins riches que ceux du littoral de la côte Est du Mont Panié. Toutes les espèces capturées sont diadromes et tous les impacts des activités humaines sur les habitats aquatiques sont très significatifs, en particulier sur les habitats estuariens. En effet ces especes doivent procéder à deux migrations entre l'eau douce et la mer. Le succès d'un tel cycle de vie - à savoir la production de larves migrant vers la mer et le repeuplement des rivières par les post-larves et juvéniles - repose sur le maintien de corridors montagne-océan fonctionnels pour permettre les mouvements entre les deux habitats.

INTRODUCTION

The freshwater fauna of New Caledonia is rich and has Australian, Indonesian and Indo-Pacific affinities. The fauna consists of 101 species: 64 fishes and 37 decapoda crustaceans. Among these 101 species, 25 (24.8%) are endemic to New Caledonia (17.2 % for fishes and 37.8 % for crustaceans) (Marquet et al., 2003; Keith et al., 2009a).

The size of the hydrographic network of New Caledonia increases with average altitude. River flows depend on various factors such as climate, soils, vegetation cover and

catchment basin morphology. Rivers and streams usually flow perpendicularly to the coast, and catchment areas are generally small. In Grande-Terre, two major types of riverine hydrosystems can be distinguished: the short and oxygenated streams in the northeast of the province Nord, generally on metamorphic substrate, and the large streams of the province Sud, generally on ultramaphic substrate.

Streams of Mt. Panié catchment share similar flow characteristics to those of streams found elsewhere in Grande Terre. However, some streams are ephemeral or may have sub-surface flows during the drier months. The run-off varies considerably, depending on the site's orographic characteristics, the season, and the forest cover. It is also liable to changes that reflect specific weather episodes linked to the tropical climate extremes such as cyclonic floods or droughts.

Between 1998 and 2003, the Museum national d'Histoire naturelle (MNHN) conducted an exhaustive inventory of freshwater fish in New Caledonia, with the help of the provincial and territorial authorities. Inventories were undertaken on the major hydrosystems of Grande-Terre and Loyalties Islands (see Marquet et al., 2003). Additional inventories were completed between 2004 and 2010 , particularly in Mt. Panié region, Côte oubliée and Bélep Islands (Keith et al., 2009b; Keith et al., 2010). Many new species were found during surveys carried out over the last decade (see Marquet et al., 2003; Keith et al., 2009; Keith et al., 2010a). In 2004, Keith et al. showed that the province Nord, and particularly the Mt. Panié area, is one of the most important sites for conservation of endemic freshwater fish (Keith et al., 2004). This RAP survey was conducted in order to improve our knowledge of species distribution in the Mt. Panié area, in order to mitigate the decline of freshwater species due to overfishing and anthropogenic disturbances.

Fish and crustacean species of Mt. Panié catchment are mainly diadromous. Diadromous fishes are migratory and alternate between freshwater and saltwater according to their life cycle. Diadromous species are classified in three sub categories:

1. Anadromous species spend the majority of their life in salt water and migrate to freshwater to reproduce (e.g., Salmonidae).
2. Catadromous species spend the majority of their life in freshwater and migrate to saltwater to reproduce (e.g., Anguillidae)
3. Amphidromous species: females spawn many ova in freshwater, which are then fertilised by the males. After hatching the larvae are carried by the current out to sea where they spend a variable amount of time (Valade et al., 2009; Lord et al., 2010; Taillebois et al., 2012). The young fry then go back to freshwater to resume their growth (Keith et al., 2008). The migration has no reproductive goal, unlike the two former categories (Fig. 1). Amphidromy is a major adaptation to insular environments (Mc Dowall, 2007), and is the main type of life cycle for the New Caledonian fish and crustaceans.

METHODS

Streams

The streams of New Caledonia can be divided into three zones defined according to the river slope, the average

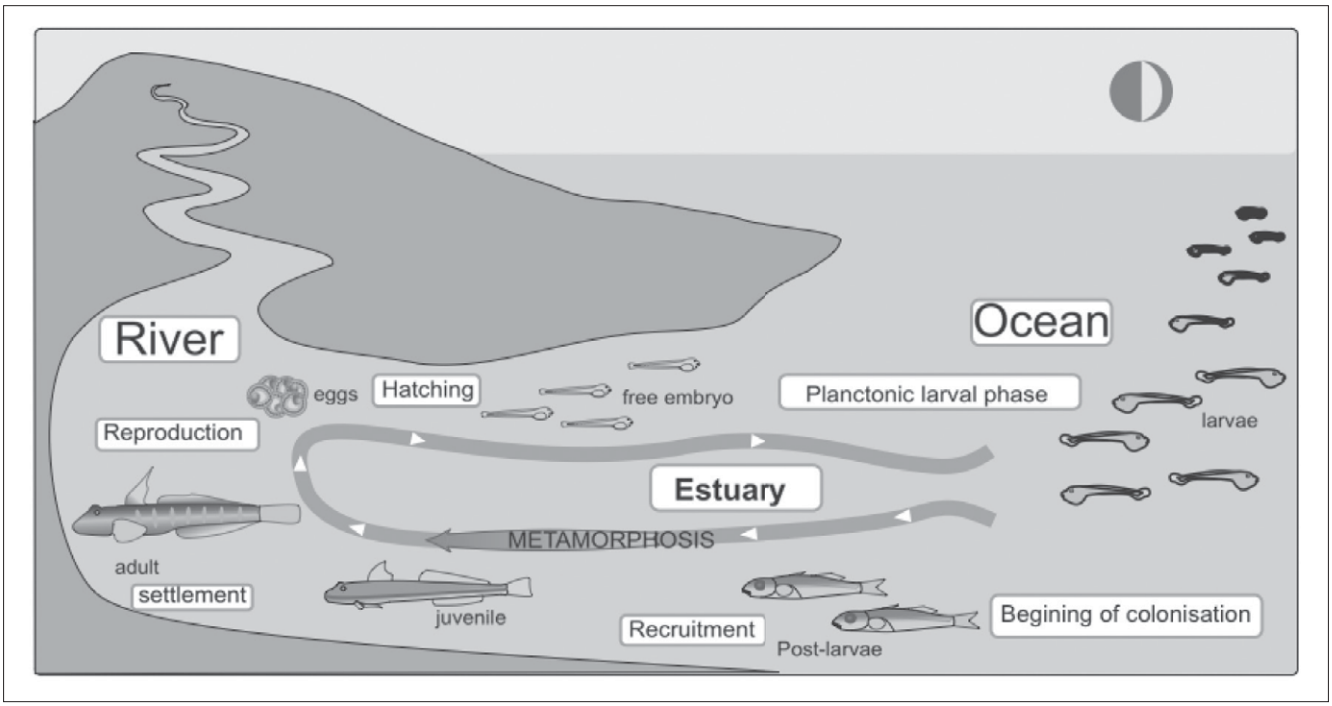

Figure 1: Amphidromy cycle for Freshwater Gobies (P. Torres/F. Keith)

current velocity and the size of the substrate: *higher course*, *middle course*, and *lower course*. These three zones represent distinct habitats for different fishes and crustaceans. Specific criteria define these three zones (Marquet et al., 2003):

*The *higher course* is characterised by a steep slope (generally more than 10%), with fast current. The substrate is usually composed of large boulders and cobbles directly coming from the parent-rock. The delimitation with the middle course often corresponds to a topographical accident, like a cascade. The distance between this reach and the river mouth is highly variable and largely depends on the catchment area's geological characteristics.

*The *middle course* has an average slope generally under 10%. The riverbed is covered in pebbles and rocks. Sometimes, sandy bottoms can be found in slow current reaches. The length of this zone depends on the geological origins of the catchment area.

* The *lower course* is the part of the stream located in the usually narrow coastal plain; its length is thus generally reduced. Two areas can be distinguished in this zone: the estuary, immediately under marine influence, and the upstream part, where the water's conductivity is lower than in estuaries.

Some estuaries can be very broad (i.e. Ouaième River), and the intrusion of salt water reaches relatively far upstream. The slope and the current speed are low to nil, resulting in a high accumulation zone of sediment. In estuaries, the sediments are composed of sand and silt, but higher upstream the grain size is coarser (gravel, pebbles and rocks). This lower course is not present in all streams, the marine influence being somewhat lesser.

There is a relation between the river course facies and the species found within each zone. The majority of species are found in facies where the current is relatively slow. On the contrary, populations found in facies where the current is very strong (rapids or steps) are characterised by the presence of species with specific adaptations to this type of environment. This is, for example, the case for gobies of the *Sicyopterus* genus that are capable of resisting very strong currents by sticking to the substrate using a ventral suction cup. In these mountainous streams where rainfall is high, one facies can quickly be replaced by another one because of the flow variability and the torrential regime. Nevertheless, the distribution of all populations of new caledonian aquatic fish and crustacean species is influenced by elevation and ecological preferences. Indeed, some species favour living exclusively in the lower course, whereas others are found only in the higher course.

Fish and crustaceans

Fishes and crustaceans were investigated from 10/10/2010 to 21/10/2010 on three sites at Mt. Panié: La Guen (4 stations), Wewec (5 stations) and Roches de la Ouaième (1 station) using electric fish sampling techniques. Mt. Panié is the highest summit of New Caledonia (1629 m), located in the central chain of Grande-Terre, and has a nature reserve of 5,400 hectares. Streams from this conservation area are very steep with a high flow-rate and consist mainly of middle and higher courses. Their beds consist of metamorphic rocks (blue schist type) and waters are very lightly mineralised (around 15–55 microS.cm-1).

A generator (Dekka Lord 2000) was used for the sampling. The portable machine that was used had a battery with an output power of 180 W. It gives rectangular impulses at a fixed frequency of 100 Hz or 400 Hz. The duty cycle is controllable and is of 5 to 25 %. It has three voltage outputs: 150, 200 and 300 V. Electric fishing is performed by wading upstream in order to keep the water clear in front of the person sampling. A fishing electrode is placed near habitat shelters in which the animals are found; the electrode creates an electrical field which has an attraction effect within a radius of a one-metre zone under average conditions. When a fish comes within this field, it is stunned, and can then be caught easily with a hand net.

Snorkeling with mask and handnets was also used as a complementary method of fishing. Each species caught was identified and, when preserved, the material was deposited in the collection of the MNHN in Paris according to the provincial permit N°60912–2320-2010/JJC.

RESULTS AND DISCUSSION

10 species of crustaceans (belonging to 6 genera) and 9 species of fish (belonging to 7 genera) were collected at the three sites (Table 1; Appendix 1). Only one species was introduced, a mosquito fish.

Out of the the 9 fish species caught during the RAP, 8 belong to Gobiidae and Anguillidae famillies. All the Gobiidae found are amphidromous and belong to the Gobionellinae (*Awaous guamensis*) or the Sicydiinae (*Sicyopterus lagocephalus*, *Smilosicyopus chloe*, *Sicyopus zosterophorum*, *Lentipes kaaea*) sub-families. The crustaceans caught are amphidromous and belong mainly to Atyidae and Palaemonidae families.

More specifically, 9 species of crustaceans and 5 species of fish belonging to respectively 5 and 4 genera were collected from La Guen sites; 7 species of crustaceans and 8 species of fish belonging to respectively 4 and 6 genera were collected from Wewec sites; and 4 species of 8 crustaceans and 2 species of fish belonging to respectively 4 and 2 genera were collected from Roches de la Ouaième site.

COMPARISON BETWEEN RAP SITES

Considering the number of genera found, La Guen sites are more diverse than Wewec sites. Considering the number of species found, crustaceans are more diverse in La Guen than in Wewec and, on the contrary, fish are more diverse in Wewec than in La Guen. Roches de la Ouaième is the poorest site in terms of fish and crustacean species richness.

Table 1: Species collected at the three different sites (*introduced)

	Species	La Guen	Wewec	Roches de la Ouaième
Fish	**Anguillidae**			
	Anguilla marmorata	✔	✔	
	Anguilla megastoma	✔	✔	✔
	Poeciliidae			
	*Poecilia reticulata**	✔		
	Gobiidae			
	Awaous guamensis		✔	
	Lentipes kaaea		✔	
	Sicyopterus lagocephalus	✔	✔	✔
	Smilosicyopus chloe		✔	
	Smilosicyopus sp		✔	
	Sicyopus zosterophorum	✔	✔	
	SUB-TOTAL	**5**	**8**	**2**
Crustaceans	**Atyidae**			
	Atyoida pilipes	✔	✔	✔
	Atyopsis spinipes	✔	✔	✔
	Paratya bouvieri	✔		
	Caridina weberi	✔	✔	
	Caridina peninsularis	✔		
	Caridina novaecaledoniae	✔	✔	
	Palaemonidae			
	Macrobrachium lar	✔	✔	✔
	Macrobrachium aemulum	✔	✔	
	Macrobrachium latimanus	✔	✔	
	Grapsidae			
	Varuna litterata			✔
	SUB-TOTAL	**9**	**7**	**4**
	Total	**14**	**15**	**6**

Fish

On La Guen river, the prospected sites above the highest elevation waterfall had no fish. Indeed, fish (except eel) do not appear to have climbed this last waterfall despite being usually able to do so elsewhere. The only site containing fish were under the first waterfall. Among the 5 species found in La Guen, one is an introduced species (*Poecilia reticulata*), 2 are Anguillidae and 2 are Sicydiinae (Gobiidae).

On Wewec river, prospected stations 1 and 2 are on the deforested side of the mountain and stations 3, 4 and 5 are on the side with pristine forest. Stations 1 and 2 supported 3 species, whereas 7 species occurred at stations 3, 4 and 5. In contrast to La Guen, we found fish above waterfalls on Wewec River. Among the 7 species found in Wewec River, one is endemic to the Vanuatu/New Caledonia region (*Smilosicyopus chloe*) and one is endemic to Vanuatu/New Caledonia/Fiji/Futuna (*Lentipes kaaea*). Another species from the genus *Smilosicyopus* was caught in Wewec river ; this species has a wide distribution in the Pacific and was already known in New Caledonia. Its exact taxonomic situation and name is still a work in progress.

Only two species were caught in the river Pwé Kedivin at Roches de la Ouaième.

Crustaceans

On La Guen river, we found 9 species of crustaceans from two families (Atyidae and Palaemonidae). Some crustaceans are excellent at climbing, that is why they could be found at higher altitudes above the waterfalls. We found two endemic

species to New Caledonia (*Paratya bouvieri* and *Caridina novaecaledoniae*).

On Wewec river, 7 species of crustaceans from two families (Atyidae and Palaemonidae) were caught. Only one endemic species was found (*Caridina novaecaledoniae*).

Only 4 species were caught in the river Pwé Kedivin at Roches de la Ouaième.

The results conform well to what is commonly found for regional fish and crustaceans in terms of altitudinal distribution (Keith et al., 2003; Keith and Lord, 2011), with species richness declining from estuary to high elevation. The fact that ecological conditions become increasingly constraining with altitude (strong current, unavailability of food) probably explains why only three species (*Sicyopterus lagocephalus, Macrobrachium lar, Anguilla marmorata*) can be found from the lower course to the higher course of the river, and that only three species live only in the higher course (*Anguilla megastoma, Lentipes kaaea, Macrobrachium latimanus*). The decline in species richness is especially strong for fish above waterfalls, which act as geographical barriers. Concerning fish species, only *Sicyopterus lagocephalus, Lentipes kaaea*, *Sicyopus zosterophorum* and *Smilosicyopus chloe, Anguilla marmorata* and *Anguilla megastoma* are able to climb waterfalls..

Comparisions of Mt. Panié area with other sites

From data obtained during the RAP survey, we conclude that the RAP sites do not have high species richness compared with others sites that have previously been sampled in the province Nord, or more broadly in New Caledonia, especially when compared to the nearby coastal rivers from the eastern side of Mt. Panié. Nevertheless, two sites in this study, Wewec and La Guen rivers, are important for the conservation of *Lentipes kaaea*, *Sicyopus zosterophorum* and *Smilosicyopus chloe,* because these species do not occur in many places outside Mt. Panié area and/or because they are threatened species.

IMPORTANT SPECIES

Endemic species

Among the species caught, one fish species endemic to the Vanuatu/New Caledonia region and one to the Vanuatu/New Caledonia/Fidji/Futuna region were found in Wewec river: *Smilosicyopus chloe* and *Lentipes kaaea* respectively. These two species were so far only known in New Caledonia from the North-eastern coast in Panié-Colnett-Ignambi-Mandjélia catchments to Poindimié (Fig. 3).

Smilosicyopus chloe occurs in clear, fast flowing (40 to 80 cm.s-1 ; Keith et al., 2004) and oxygen rich streams.

It prefers rocky substrate. It is found in middle and higher courses of rivers, up to an altitude of 50 to 100 m. It is carnivorous and feeds on small aquatic insects and crustaceans (Watson et al., 2001). This species is amphidromous. After reproduction, larvae are carried to sea where they stay several months. They recolonise fresh water when they reach the juvenile stage (Marquet et al., 2003; Keith et al., 2010b). It is listed 'Least concerned' by the IUCN on the red list of threatened species.

Lentipes kaaea occurs in small, clear and oxygen-rich streams. It lives on rocky substrate, in fast flowing currents (between 30 and 80 $cm.s^{-1}$; Keith et al., 2004) or in counter-currents and up to 200 to 300 m in altitude. It is probably one of the species capable of migrating further upstream. It lives on the bottom or swims freely in its territory, especially during courtship. The species is amphidromous: during reproduction, the female lays the eggs on top of rocks. Larvae travel to sea after hatching, where they remain for several months. When larvae reach 13 to 16 mm, they return to fresh water to resume growth (Marquet et al., 2003; Keith et al., 2010b). It is listed 'Least concerned' by the IUCN on the red list of threatened species.

Two endemic crustaceans species from New Caledonia were found in La Guen (*Paratya bouvieri* and *Caridina novaecaledoniae*) and one in Wewec (*Caridina novaecaledoniae*). Both species are found in the lower and mid courses of the rivers. They can be found in zones where the current is slow (under 30 $cm.s^{-1}$) and rich in vegetation debris, as well as in zones where the current is strong (0.25 to 2 $m.s^{-1}$), on gravels and stone substrates. Both species are detritivores, feeding on detritus and algae by scraping and picking them off the rocks with both claws, which are extended by long setae.

All of these freshwater fish and crustaceans species are indicators of good water quality (Keith, 2003), and they are somewhat threatened by anthropogenic alterations (see recommendations).

Threatened, indicator and key species

Other species are also threatened and/or represent indicator or key species, including *Anguilla marmorata* (the Giant mottled-eel), *Anguilla megastoma* (Polynesian Longfinned Eel), *Sicyopus zosterophorum*, *Sicyopterus lagocephalus* (Red-tailed Goby), *Macrobrachium lar* and *Macrobrachium latimanus*.

Anguilla marmorata (the Giant mottled-eel) occurs both in the Indian and Pacific Oceans. It lives in fast flowing water from estuaries to the higher reaches, but it can also be found in stagnant waters. It feeds at night. Young eels feed on prawn larvae (*Macrobrachium*) and fish fry. Giant mottled-eels have a weakly developed caudal spot whereas their medio-lateral line bears many melanophores. Glass eels arrive in estuaries between October and April, with a peak season in January-February. Glass eels measure 47 to 57 mm (Marquet et al., 2003). The species is present across the Indo-Pacific area and is highly fished (Keith et al., 2010b) and is listed 'Least concerned' by the IUCN on the red list of threatened species.

Anguilla megastoma (Polynesian Longfinned Eel) is found in the Pacific area (Solomon Islands, French Polynesia, Vanuatu, New Caledonia, Pitcairn, etc.). It lives in the

higher reaches of the rivers and is an indicator of good water quality (Keith et al., 2010b). It feeds at night. It eats crustaceans (prawns) and fish. Glass eels have a relatively well-developed caudal spot whereas the medio-lateral line has few melanophores. Glass eels arrive in estuaries between April and July. They measure 47 to 49 mm (Marquet et al., 2003). Less common than *Anguilla marmorata* and also fished, this eel need to be given the highest level of protection and should be monitored in New Caledonia.

Sicyopus zosterophorum is found from Sumatra in the Indian Ocean and southern Japan to Vanuatu, New Caledonia and Fiji. This species occurs in clear, fast flowing and oxygen rich streams. It prefers substrate with pebbles and cobbles. It is found in the middle course of the river, up to 200 m in altitude. It is carnivorous and feeds on small aquatic insects and crustaceans. It is an amphidromous species. After reproduction, larvae are carried to sea where they stay several months. They recolonise fresh water after a couple months spent in the sea (Taillebois et al., 2012). This species is an indicator of good water quality (Keith et al., 2010b).

Sicyopterus lagocephalus (Red-tailed Goby) adults are extremely rheophilic and they generally live in fast flowing zones with fast current (130 to 160 $cm.s^{-1}$) in more or less deep areas (20 to 40 cm deep). They adhere to pebbles and cobbles using a ventral sucker. It feeds by scraping diatoms from the rocky substrate. This species is amphidromous and reproduces in rivers. The female lays 50,000 to 70,000 eggs. The embryonic development takes place in fresh water. The larvae are carried to sea after hatching where they develop into post-larvae. When this competent stage is reached (after nearly 130 to 240 days spent at sea), they regroup near river mouths in order to start migrating upstream. It seems that post-larvae are drawn to fresh water flowing into the sea along coastal zones. With their sucker, they can climb waterfalls and therefore colonise high elevation streams (Lord et al., 2010). This species is widespread in the Indo-Pacific area; it occurs in the Western Indian Ocean, from the Comoros Islands to the Mascarenes, and in the Pacific, in New Caledonia and Vanuatu, as far as French Polynesia and Japan. *Sicyopterus lagocephalus* is an indicator of good water quality (Lord et al., 2010) and is listed 'Least concerned' by the IUCN on the red list of threatened species.

Finally, the two *Macrobrachium* prawns are fished in many rivers in New Caledonia and need to be protected.

Macrobrachium lar (Giant jungle prawn) is found in the Indo-Pacific region (East-African coasts, Seychelles, Mascarenes, Philippines, Indonesia, Vanuatu, New Caledonia, Philippines, Fiji and French Polynesia). This species is found in the rivers from the lower to the higher courses. It colonises well oxygenated streams as well as river mouths. This species is amphidromous. The reproduction takes place in fresh or brackish waters. Courtship behaviour precedes mating. The eggs are relatively small and a single female can carry more than 40,000. The incubation period lasts about 20 days (Marquet et al., 2003). There are ten larval stages. After hatching the larvae are carried to sea. The juveniles migrate towards freshwater as they reach 30 to 35 mm in length. The feeding habits of this species are varied and omnivorous (Keith et al., 2010b).

Macrobrachium latimanus (Mountain river prawn) is found in the Indo-Pacific region (Western Indian coast, Japan, Fiji, Vanuatu, New Caledonia and French Polynesia). This species is found in the medium course of rivers but mostly in the higher courses, in zones where the current is medium to strong, in water pits and cascades (Keith et al., 2010). It prefers substrates with pebbles, rocks and boulders enabling it to hide easily. In these zones the water temperature rarely exceeds 20° C and they are well oxygenated. The species is amphidromous. *Macrobrachium latimanus* has an omnivorous feeding mode, and is quite opportunistic (Keith et al., 2010b).

The Noreil *Rhyacichthys guilberti* was not found during the RAP, even though its original range in New Caledonia included the area between the Ouaième River and the Tité River. It appears to have disappeared prior to 1985 from the Ouaième River, and seems very rare in New Caledonia, if not extinct. In Vanuatu, where the species is still present, it prefers clear, well oxygenated waters, both in gently sloping rivers and in wider streams. It inhabits a restricted river stretch, between the estuary and the first impassable cascade. The species is benthic and probably nocturnal. *Rhyacichthys* belongs to the most specialized group of hill-stream fish characterized by their depressed bodies, by various attachment mechanisms, and by an herbivorous and insectivorous diet of algae and insects plucked from the surface of stones.

CONSERVATION RECOMMENDATIONS

It has been commonly found in many studies that, in the surveyed areas, the number of species is greater in rivers flowing under natural vegetation cover and where the flow is unmodified (Keith, 2003; Keith and Lord, 2011). This is confirmed in the Mt. Panié RAP, where the deforested sites (Wewec) supported fewer species than forested sites. This result is likely explained by current knowledge about amphidromous species and their dependence on intact river-forest systems (see Keith 2003). Intact vegetation cover regulates river flow and maintains cool temperatures and well-oxygenated water. Riparian vegetation produces exogenous food inflows for aquatic species, which is especially important in insular river systems which are generally poor in nutritional elements. The vegetation cover thus raises the river's trophic complexity, while favouring habitat diversity (shelter for crustaceans for example) and water filtration (Keith et al., 2010b).

Amphidromous species colonising the rivers are distributed along the river from the estuary to the higher reaches according to their ecology. Some are therefore only found at a certain altitude according to physical and chemical parameters of the aquatic environment, including water temperature. The majority of species encountered during

the Mt. Panié RAP are rheophilic (living in strong currents). This is particularly the case for the endemic and key species caught. In order to maintain a high level of biodiversity, it is therefore necessary to maintain high flow rates. The seasonal variability favours massive freshwater flow in estuaries, thus allowing post-larvae from the sea to colonise the rivers.

Moreover, the shorter the river and steeper its slope, the higher the success of downstream migration of larvae to the sea. Fish larvae have less than three days after hatching to reach the estuary. In these kinds of rivers, the colonisation of rivers by post-larvae will also be more successful. As they return, they must climb upstream as fast as possible in order to escape predators which predominate in the lower course and to find suitable territory.

The current state of knowledge on the life cycle of diadromous species (biology, ecology) of New Caledonia, the length of the larval phase and the part it plays in the dispersal of larvae, is of direct relevance to management and conservation. The management and the conservation of species must take into account both the dependency of adult populations on the larval pool for replacement, and the contribution of each reproductive population to the larval pool (Murphy and Cowan, 2007). The length of the marine phase might increase the probability of finding a river for colonisation, as will the strength and the direction of marine currents. The survival of species in New Caledonia depends also on the ability of existing populations to provide enough larvae to maintain appropriate adult numbers. The Mt. Panié region is one of the main population sources for several endemic species and needs to be protected, particularly its pristine forested areas.

Seasonal variables (e.g., rainfall, drought, floods, typhoons, etc.) have a major impact on the survival of populations. Biological events such as reproduction, spawning, and the dispersal of larvae, are dependent on these events and are synchronised with them. Anthropogenic impact on aquatic habitats -that are usually restricted on islands- is strong, particularly in estuarine habitats which are crucial for amphidromous species that migrate between freshwater and the sea. The success of such a life cycle, i.e., production of larvae and restocking rivers in the study area, depends on maintaining the mountain-ocean corridor in Ouaième river to allow movement between both habitats.

It is essential to allow species to move freely between the upstream and downstream reaches for trophic or gamic migrations or for downstream migration of larvae, as well as between the downstream and upstream reaches for river colonisation by post-larvae and juveniles. Ensuring free circulation of these species requires that there are no geographic barriers in the river that cannot be crossed both up and downstream, although the ecological and biological characteristics of these species still need to be studied. It is also important to note that fishways are effective only if adapted to the requirements of individual fish species.

The different ecological studies carried out show that a minimum flow has to be maintained in order to maintain rheophilic zones (strong current and high water oxygenation) in the river and thus enable the species adapted to such an environment to complete their biological cycle. The flow rates must be high and must follow seasonal variations: freshwater discharging into the sea attracts post-larvae which then colonise the rivers. The disappearance of these rheophilic areas would rapidly lead to the extinction of these endemic species.

The riparian vegetation cover must be maintained or restored along rivers. This forest cover ensures that the water remains cool and well oxygenated. It also ensures regular rainfall supplying the catchment area with water. Forest cover provides a high diversity of habitats and therefore of species. It also supplies exogenous elements for the nourishment of certain species.

The installation of structures modifying the flow rate, degrading habitats or causing pollution should be avoided. River eutrophication (as it could be seen in some parts of Ouaième river) would lead to the disappearance of rare and/or endangered species because of the modification of the physical and chemical parameters of the water. Moreover, the proliferation of filamentous algae could restrain the development of amphidromous species which graze short algae from pebbles and rocks.

The Ouaième river estuary must be preserved in its natural state, since it encompasses key areas where certain species disperse: larvae of amphidromous species exit to sea and post-larvae and juveniles from the sea colonise rivers.

Although prawn (*Macrobrachium lar, Macrobrachium latimanus*) fisheries are a tradition in New Caledonia, this type of exploitation may be unsustainable when used during the reproductive period (november-december). In the long run, this is likely to lead to a decline of stocks, as it has already been observed around Mt. Panié by local communities (cf Mt. Panié reserve management plan). People harvesting prawns and fish may however not be the single, nor the main threat in the study area. Regulation of prawn fisheries, such as in Réunion Island or French Polynesia, should be introduced.

Finally, urgent studies on the life cycle and ecology of diadromous species, especially gobies and eels, are needed. Man-made developments on these streams can alter larval dispersion and therefore recruitment success. Consequently, it is necessary to understand the biology of these species in order to develop regional management and restoration strategies.

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Appendix 1

Genus	Species	Date_obs	X_coord	Y_coord	Locality	T°	Conductivity
Anguilla	*marmorata*	11/10/10	164°47'59,874" E	20°38'29,178" S	La Guen ST_1	21.5 °C	18 µS/cm
Poecilia	*reticulata*	11/10/10	164°47'59,874" E	20°38'29,178" S	La Guen ST_1	21.5 °C	18 µS/cm
Sicyopterus	*lagocephalus*	11/10/10	164°47'59,874" E	20°38'29,178" S	La Guen ST_1	21.5 °C	18 µS/cm
Sicyopus	*zosterophorum*	11/10/10	164°47'59,874" E	20°38'29,178" S	La Guen ST_1	21.5 °C	18 µS/cm
Atyoida	*pilipes*	11/10/10	164°47'59,874" E	20°38'29,178" S	La Guen ST_1	21.5 °C	18 µS/cm
Atyopsis	*spinipes*	11/10/10	164°47'59,874" E	20°38'29,178" S	La Guen ST_1	21.5 °C	18 µS/cm
Paratya	*bouvieri*	11/10/10	164°47'59,874" E	20°38'29,178" S	La Guen ST_1	21.5 °C	18 µS/cm
Caridina	*weberi*	11/10/10	164°47'59,874" E	20°38'29,178" S	La Guen ST_1	21.5 °C	18 µS/cm
Caridina	*peninsularis*	11/10/10	164°47'59,874" E	20°38'29,178" S	La Guen ST_1	21.5 °C	18 µS/cm
Macrobrachium	*lar*	11/10/10	164°47'59,874" E	20°38'29,178" S	La Guen ST_1	21.5 °C	18 µS/cm
Macrobrachium	*aemulum*	11/10/10	164°47'59,874" E	20°38'29,178" S	La Guen ST_1	21.5 °C	18 µS/cm
Atyopsis	*spinipes*	12/10/10	164°46'52,518" E	20°37'27,678" S	Kompwara ST_2	18.5 °C	15 µS/cm
Paratya	*bouvieri*	12/10/10	164°46'52,518" E	20°37'27,678" S	Kompwara ST_2	18.5 °C	15 µS/cm
Caridina	*weberi*	12/10/10	164°46'52,518" E	20°37'27,678" S	Kompwara ST_2	18.5 °C	15 µS/cm
Macrobrachium	*aemulum*	12/10/10	164°46'52,518" E	20°37'27,678" S	Kompwara ST_2	18.5 °C	15 µS/cm
Macrobrachium	*latimanus*	12/10/10	164°46'52,518" E	20°37'27,678" S	Kompwara ST_2	18.5 °C	15 µS/cm
Atyopsis	*spinipes*	12/10/10	164°46'54,150" E	20°37'25,986" S	La Guen ST_3	17.5 °C	15 µS/cm
Paratya	*bouvieri*	12/10/10	164°46'54,150" E	20°37'25,986" S	La Guen ST_3	17.5 °C	15 µS/cm
Caridina	*weberi*	12/10/10	164°46'54,150" E	20°37'25,986" S	La Guen ST_3	17.5 °C	15 µS/cm
Macrobrachium	*aemulum*	12/10/10	164°46'54,150" E	20°37'25,986" S	La Guen ST_3	17.5 °C	15 µS/cm
Anguilla	*megastoma*	13/10/10			La Guen ST_4	17.7 °C	15 µS/cm
Sicyopterus	*lagocephalus*	13/10/10			La Guen ST_4	17.7 °C	15 µS/cm
Atyoida	*pilipes*	13/10/10			La Guen ST_4	17.7 °C	15 µS/cm
Atyopsis	*spinipes*	13/10/10			La Guen ST_4	17.7 °C	15 µS/cm
Paratya	*bouvieri*	13/10/10			La Guen ST_4	17.7 °C	15 µS/cm
Caridina	*novaecaledoniae*	13/10/10			La Guen ST_4	17.7 °C	15 µS/cm
Caridina	*weberi*	13/10/10			La Guen ST_4	17.7 °C	15 µS/cm
Macrobrachium	*aemulum*	13/10/10			La Guen ST_4	17.7 °C	15 µS/cm
Macrobrachium	*latimanus*	13/10/10			La Guen ST_4	17.7 °C	15 µS/cm
Awaous	*guamensis*	15/10/10	164°43'41,340" E	20°35'39,342" S	Pwé Teao ST_5	18.5 °C	55 µS/cm
Sicyopterus	*lagocephalus*	15/10/10	164°43'41,340" E	20°35'39,342" S	Pwé Teao ST_5	18.5 °C	55 µS/cm
Sicyopus	*zosterophorum*	15/10/10	164°43'41,340" E	20°35'39,342" S	Pwé Teao ST_5	18.5 °C	55 µS/cm
Atyoida	*pilipes*	15/10/10	164°43'41,340" E	20°35'39,342" S	Pwé Teao ST_5	18.5 °C	55 µS/cm
Atyopsis	*spinipes*	15/10/10	164°43'41,340" E	20°35'39,342" S	Pwé Teao ST_5	18.5 °C	55 µS/cm
Caridina	*novaecaledoniae*	15/10/10	164°43'41,340" E	20°35'39,342" S	Pwé Teao ST_5	18.5 °C	55 µS/cm
Macrobrachium	*lar*	15/10/10	164°43'41,340" E	20°35'39,342" S	Pwé Teao ST_5	18.5 °C	55 µS/cm
Macrobrachium	*latimanus*	15/10/10	164°43'41,340" E	20°35'39,342" S	Pwé Teao ST_5	18.5 °C	55 µS/cm
Sicyopterus	*lagocephalus*	15/10/10	164°43'57,240" E	20°36'28,938" S	Wewec ST_6	18.5 °C	55 µS/cm
Atyoida	*pilipes*	15/10/10	164°43'57,240" E	20°36'28,938" S	Wewec ST_6	18.5 °C	55 µS/cm
Atyopsis	*spinipes*	15/10/10	164°43'57,240" E	20°36'28,938" S	Wewec ST_6	18.5 °C	55 µS/cm
Caridina	*novaecaledoniae*	15/10/10	164°43'57,240" E	20°36'28,938" S	Wewec ST_6	18.5 °C	55 µS/cm
Macrobrachium	*lar*	15/10/10	164°43'57,240" E	20°36'28,938" S	Wewec ST_6	18.5 °C	55 µS/cm
Macrobrachium	*aemulum*	15/10/10	164°43'57,240" E	20°36'28,938" S	Wewec ST_6	18.5 °C	55 µS/cm
Macrobrachium	*latimanus*	15/10/10	164°43'57,240" E	20°36'28,938" S	Wewec ST_6	18.5 °C	55 µS/cm
Lentipes	*kaaea*	16/10/10	164°44'16,920" E	20°35'29,922" S	Pwé Tiera ST_7	21°C	43 µS/cm

Genus	Species	Date_obs	X_coord	Y_coord	Locality	T°	Conductivity
Sicyopterus	*lagocephalus*	16/10/10	164°44'16,920" E	20°35'29,922" S	Pwé Tiera ST_7	21°C	43 µS/cm
Sicyopus	*zosterophorum*	16/10/10	164°44'16,920" E	20°35'29,922" S	Pwé Tiera ST_7	21°C	43 µS/cm
Atyoida	*pilipes*	16/10/10	164°44'16,920" E	20°35'29,922" S	Pwé Tiera ST_7	21°C	43 µS/cm
Atyopsis	*spinipes*	16/10/10	164°44'16,920" E	20°35'29,922" S	Pwé Tiera ST_7	21°C	43 µS/cm
Macrobrachium	*aemulum*	16/10/10	164°44'16,920" E	20°35'29,922" S	Pwé Tiera ST_7	21°C	43 µS/cm
Macrobrachium	*latimanus*	16/10/10	164°44'16,920" E	20°35'29,922" S	Pwé Tiera ST_7	21°C	43 µS/cm
Anguilla	*megastoma*	17/10/10	164°44'7,356" E	20°36'54,402" S	Wé Djao ST_8	20.5 °C	39 µS/cm
Lentipes	*kaaea*	17/10/10	164°44'7,356" E	20°36'54,402" S	Wé Djao ST_8	20.5 °C	39 µS/cm
Sicyopterus	*lagocephalus*	17/10/10	164°44'7,356" E	20°36'54,402" S	Wé Djao ST_8	20.5 °C	39 µS/cm
Smilosicyopus	*chloe*	17/10/10	164°44'7,356" E	20°36'54,402" S	Wé Djao ST_8	20.5 °C	39 µS/cm
Sicyopus	*zosterophorum*	17/10/10	164°44'7,356" E	20°36'54,402" S	Wé Djao ST_8	20.5 °C	39 µS/cm
Smilocyopus	sp	17/10/10	164°44'7,356" E	20°36'54,402" S	Wé Djao ST_8	20.5 °C	39 µS/cm
Atyoida	*pilipes*	17/10/10	164°44'7,356" E	20°36'54,402" S	Wé Djao ST_8	20.5 °C	39 µS/cm
Atyopsis	*spinipes*	17/10/10	164°44'7,356" E	20°36'54,402" S	Wé Djao ST_8	20.5 °C	39 µS/cm
Caridina	*weberi*	17/10/10	164°44'7,356" E	20°36'54,402" S	Wé Djao ST_8	20.5 °C	39 µS/cm
Macrobrachium	*aemulum*	17/10/10	164°44'7,356" E	20°36'54,402" S	Wé Djao ST_8	20.5 °C	39 µS/cm
Macrobrachium	*latimanus*	17/10/10	164°44'7,356" E	20°36'54,402" S	Wé Djao ST_8	20.5 °C	39 µS/cm
Anguilla	*marmorata*	18/10/10	164°44'9,084" E	20°35'38,928" S	Wewec ST_9	21.2 °C	28 µS/cm
Lentipes	*kaaea*	18/10/10	164°44'9,084" E	20°35'38,928" S	Wewec ST_9	21.2 °C	28 µS/cm
Sicyopterus	*lagocephalus*	18/10/10	164°44'9,084" E	20°35'38,928" S	Wewec ST_9	21.2 °C	28 µS/cm
Smilosicyopus	*chloe*	18/10/10	164°44'9,084" E	20°35'38,928" S	Wewec ST_9	21.2 °C	28 µS/cm
Smilosicyopus	sp	18/10/10	164°44'9,084" E	20°35'38,928" S	Wewec ST_9	21.2 °C	28 µS/cm
Sicyopus	*zosterophorum*	18/10/10	164°44'9,084" E	20°35'38,928" S	Wewec ST_9	21.2 °C	28 µS/cm
Atyopsis	*spinipes*	18/10/10	164°44'9,084" E	20°35'38,928" S	Wewec ST_9	21.2 °C	28 µS/cm
Macrobrachium	*lar*	18/10/10	164°44'9,084" E	20°35'38,928" S	Wewec ST_9	21.2 °C	28 µS/cm
Macrobrachium	*aemulum*	18/10/10	164°44'9,084" E	20°35'38,928" S	Wewec ST_9	21.2 °C	28 µS/cm
Macrobrachium	*latimanus*	18/10/10	164°44'9,084" E	20°35'38,928" S	Wewec ST_9	21.2 °C	28 µS/cm
Atyopsis	*spinipes*	19/10/10	164°44'56,940" E	20°37'53,256" S	Wewec ST_10	24.3 °C	34 µS/cm
Caridina	*weberi*	19/10/10	164°44'56,940" E	20°37'53,256" S	Wewec ST_10	24.3 °C	34 µS/cm
Macrobrachium	*lar*	19/10/10	164°44'56,940" E	20°37'53,256" S	Wewec ST_10	24.3 °C	34 µS/cm
Macrobrachium	*aemulum*	19/10/10	164°44'56,940" E	20°37'53,256" S	Wewec ST_10	24.3 °C	34 µS/cm
Anguilla	*megastoma*	21/10/10	164°51'52,300" E	20°37'57,100" S	Pwé Kedivin ST_11	21.1 °C	45 µS/cm
Sicyopterus	*lagocephalus*	21/10/10	164°51'52,300" E	20°37'57,100" S	Pwé Kedivin ST_11	21.1 °C	45 µS/cm
Atyoida	*pilipes*	21/10/10	164°51'52,300" E	20°37'57,100" S	Pwé Kedivin ST_11	21.1 °C	45 µS/cm
Atyopsis	*spinipes*	21/10/10	164°51'52,300" E	20°37'57,100" S	Pwé Kedivin ST_11	21.1 °C	45 µS/cm
Macrobrachium	*lar*	21/10/10	164°51'52,300" E	20°37'57,100" S	Pwé Kedivin ST_11	21.1 °C	45 µS/cm
Varuna	*litterata*	21/10/10	164°51'52,300" E	20°37'57,100" S	Pwé Kedivin ST_11	21.1 °C	45 µS/cm