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Anguilliform fish reveal large scale contamination by mine trace elements in the coral reefs of New Caledonia

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HIGHLIGHTS

- Coral fish of New Caledonia are highly contaminated by various trace elements.
- The main trace elements (e.g. Ni, Cr, Co) are typical from mining activity.
- This contamination extends from the coast to the barrier reef.
- Thus, the whole lagoon may well be contaminated.

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ABSTRACT

Due to intensive mining activity, increasing urbanization and industrialization, vast amounts of contaminants are discharged into the lagoon of New Caledonia, one of the largest continuous coral reef systems and a major biodiversity hotspot. The levels of 11 trace element concentrations were examined in the muscles of predator fish in the south-western lagoon (moray eels and congers). These species are sedentary, widespread, abundant, and they are easily collected using a sea snake sampling technique. We found the highest mean and maximal concentrations of different trace elements ever found in coral fish, notably regarding trace elements typical from mining activity (e.g., mean values for Cr and Ni, respectively: 5.53 ± 6.99 μg g^{-1} [max, 35.7 μg g^{-1}] and 2.84 ± 3.38 μg g^{-1} [max, 18.0 μg g^{-1}]). Results show that important trace element contamination extends throughout the lagoon to the barrier reef, following a concentration gradient from the oldest nickel factory (Nouméa).

1. Introduction

The lagoons of New Caledonia, SW Pacific Ocean spread over a very large area (24,000 km^2). They are one of the largest sanctuaries for the marine diversity of the planet; it is therefore of prime importance to identify and assess potential threats to these biodiversity hotspots (Myers et al., 2000).

Increasing world demand for strategic metals, nickel (Ni) and cobalt (Co) for instance (Manheim, 1986; Parkinson, 2005), resulted in an intense exploitation of ores, the construction of new factories and the opening of new open sky mines in New Caledonia. Currently, Ni and Co extraction necessitates processing extremely large amounts of garnierites, laterites and saprolites, typical ores with low Ni and Co content (e.g. 1.5% of Ni in some mines, http://www.sln.nc). This involves total forest clearing of vast land surfaces, and thus entails strong erosion because the climate regime of New Caledonia is characterized by an alternation of dry and wet seasons, episodic cyclones, and torrential hydrological regimes (Pesin et al., 1995). For instance, the mine and nickel factory complex recently established in the Bay of Prony (Goro-Nickel, Vale Inco, 22°19′S–166°55′E) spreads out over 500 km^2; in addition the factory will discharge 10 million cubic meters per year of effluents in the lagoon (Massabuau et al., 2006; http://www.vale.nc/activites/i_usine). Another large nickel factory (SLN, Société Le Nickel) situated in the Nouméa harbor is functioning since more than a century and is provisioned by seven mining sites spread across New Caledonia (http://www.sln.nc). The overall mining activities generate massive sediment deposits (Bird et al., 1984; Ambatsian et al., 1997; Ouillon et al., 2010; Garcin et al., 2013) and a marked metal contamination of the coastal seawaters (Hédouin et al., 2009) that may threaten coral reefs (Walker and Ormond, 1982; Rogers, 1990).

However, possible environmental impact of mine industry on coral reefs remains unclear. Indeed, Nouméa (the main city) and surroundings

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are fast developing urbanized and industrialized areas where approximately 250,000 people exert strong environmental pressure (Cantin et al., 2007; Lewis et al., 2009). Large amounts of polluted waters are directly discharged into the sea. The capacities of the existing water-treatment plants are critically insufficient (<50% of the requirements, A2EP, 2009). The respective impacts of related mining activities compared to other anthropogenic activities on the reef ecosystems have not been quantified. Although biomonitoring surveys have been carried out to examine some of these issues (Metian et al., 2008, 2013; Chouvelon et al., 2009; Hédouin et al., 2009), the impact of urban and industrial pollution on the reef ecosystems in the lagoon of New Caledonia is still a major issue. No information is available regarding large scale contaminations (either regarding trace element or persistent organic pollutants, POPs) or large scale environmental impact caused by pollution (Lewis et al., 2012; Rhind, 2009).

The respective signatures associated with metallic contaminants stemming from urban activities versus Ni exploitation industries are different (Mihaylov et al., 2000; Hédouin et al., 2008; Metian et al., 2008; Hao et al., 2013). Theoretically, this difference provides means to distinguish the sources of contamination. In practice contamination processes are often complex and unclear when examined across large spatial scales and different taxa are generally used to monitor geographical variations of bioavailable metal concentrations in their environment (Rainbow, 1995; Bustamante et al., 2003). Using widely distributed organisms accessible all year round may provide comparative data across the entire lagoon and would permit to take into account seasonal fluctuations (Burger, 2006). Importantly, the selected organisms must be sedentary to ensure that information is spatially precise. Further, using predators enable to integrate underlying trophic levels. Finally, a low-cost, efficient and fast sampling (thus simple) technique is desired.

In New Caledonia, anguilliform fish fulfill these criteria. These predators are widespread and abundant in the whole lagoon (Ineich et al., 2007; Brischoux and Bonnet 2008). Following a pelagic larval stage, they settle on the seafloor and become sedentary (Abrams et al., 1983). More generally, fish are considered as efficient bio-indicators to assess contamination in marine ecosystems (Gopal et al., 1997; van der Oost et al., 2003; Ashraf et al., 2012). Recent researches showed that using specialized top-predators (sea kraits, *Laticauda* spp.), and large numbers of anguilliform fish can be easily collected all year round in the coral reefs of the western Pacific Ocean (Reed et al., 2002; Brischoux et al., 2007, 2009a, 2009b; Bonnet, 2012). Two species of amphibious sea kraits (*Laticauda laticaudata* and *Laticauda saintgironsi*) are very abundant and widespread in New Caledonia (Bonnet, 2012). Tens of thousands of snakes prospect the seafloor around their home islet and come back on land to digest where they can be easily captured. They swallow their prey whole; a gentle forced regurgitation enabled to collect the fish without consequence for the snakes (Fauvel et al., 2012). They are philopatric and sedentary (Brischoux et al., 2009c). Using the network of sea krait colonies spread across the entire lagoon, including coastal sites and remote islets, most of the reef ecosystems can be monitored with a high spatial resolution (Bonnet, 2012).

Although many contamination studies have been conducted in fish, concentration levels of some important trace elements such as Co, Cr, Mn, Ni, Se, and V have rarely been investigated (Eisler, 2010; Metian et al., 2013). These later elements were analyzed in the present study to generate baseline data on sedentary tropical fish. The first mandatory issue to gauge the possible usefulness of anguilliform fish to probe contamination status of the lagoon is to examine to what extent anguilliform fish actually accumulate trace elements: very low concentrations or a lack of variation (e.g. among individuals, sites…) would make these organisms useless for ecotoxicology investigations. Consequently, the following questions were examined in the present study: (i) Do anguilliform fish accumulate trace element contaminants? (ii) Do contamination levels vary spatially? And, (iii) do contaminant levels correlate differentially with respect to mining or urban sources?

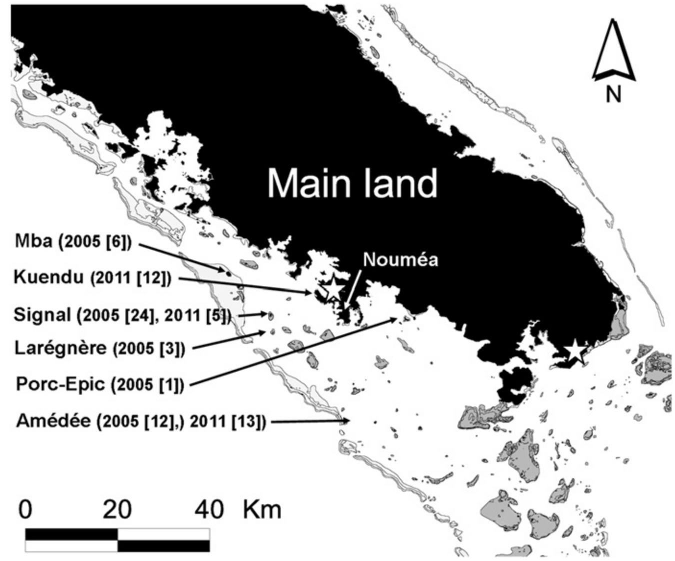

Fig. 1. Map of the study area. In each study site sampling year and sample size (N) are indicated. The two stars show two nickel factories (SLN near Nouméa and Goro Nickel at the southern tip of the main land). Black areas indicate emergent land (mainland and islands); gray areas represent coral reef flats. The barrier reef and other fringing reefs are represented by light gray areas. Kuendu and Porc Epic are close to the mainland (Costal Sites), Amédée is near the barrier reef (Barrier Reef Site), and the others (e.g. Signal) are in an intermediate situation (Mid-Lagoon Sites).

2. Materials and methods

2.1. Study sites

Study sites were situated in the Southwest lagoon, encompassing an important ~25 km spatial gradient between the coast and the barrier reef (Fig. 1). Anguilliform fish were sampled during two main periods: summers 2005 and 2011. We aimed to assess presumably heavily contaminated sites (e.g. Kuendu beach, nearby a nickel factory and the main urban and industrialized area, Fig. 1) and presumably less/not impacted sites (e.g. Amédée Island, nearby the barrier reef and thus largely influenced by the open ocean, Fig. 1). From 2005 to 2011, in the course of a long-term study, several sites where added (Bonnet, 2012). For analyses three main site categories were considered along the coast–barrier reef gradient (Fig. 1): a) near the mainland (2 coastal sites, CS), b) intermediate situation between the coast and the barrier reef (3 mid-lagoon sites, MS), and c) remote site near the barrier reef (1 barrier reef site, BS).

Table 1
List of the anguilliform fish sampled (second column) for their trace element content. Several fish were not accurately identified (e.g., head + half of the body missing). Predator refers to the sea krait from which the fish were obtained: LS stands for *Laticauda saintgironsi*; LL stands for *Laticauda laticaudata*.

Year	Fish species	Predator species	
		LS	LL
2005	*Conger spp.*	3	6
2011	*Conger spp.*	2	15
2005	*Gymnothorax albimarginatus*	0	9
2011	*G. chilospilus*	11	1
2005	*G. fimbriatus*	8	0
2005	*G. margaritoforus*	10	0
2005	*Myrophis microchir*	0	10
2005	Unidentified	2	2
2011	Unidentified	0	1
	Total	36	44