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Photo: Pascal Villard

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Habitat selection by the Ringed Kingfisher (*Megaceryle torquata stictipennis*) on Basse-Terre, Guadeloupe: possible negative association with chlordecone pollution

Pascal Villard*[1,2], Alain Ferchal[3], Philippe Feldmann[1,4], Claudie Pavis[1,5] and Christophe Bonenfant[6]

Abstract In the Lesser Antilles, the Ringed Kingfisher (*Megaceryle torquata stictipennis*) is only found in Martinique, Dominica, and Guadeloupe. In Martinique and Guadeloupe, farmers growing bananas used the insecticide chlordecone extensively from 1973 until 1993. Chlordecone is a remnant organochlorine insecticide that bioaccumulates in organisms easily. In 2009, we conducted a survey of the Ringed Kingfisher on Basse-Terre, Guadeloupe, traveling 270 km along 44 rivers to assess the effects of chlordecone on habitat selection behavior. During our survey, we encountered 47 Ringed Kingfishers, which we estimated to be 16 different individuals. A habitat selection analysis revealed that the Ringed Kingfishers were located mainly in sections of rivers flowing through the ombrophilous forest but were absent on the ocean shoreline and in the lower parts of rivers. The Ringed Kingfisher's distribution in Guadeloupe could be negatively associated with areas heavily polluted by chlordecone. We propose that the widespread use of chlordecone in banana plantations in Guadeloupe had adverse ecological consequences and may be responsible for the absence of Ringed Kingfishers in lowland habitats on the island.

Keywords Antilles, bioindicator, chlordecone, habitat selection, *Megaceryle torquata*, Ringed Kingfisher, soil pollution

Resumen Selección de hábitat por *Megaceryle torquata stictipennis* en Basse-Terre, Guadalupe: posible asociación negativa con la contaminación por clordecona • En las Antillas Menores, *Megaceryle torquata stictipennis* solamente se encuentra en Martinica, Dominica y Guadalupe. En Martinica y Guadalupe, los agricultores que cultivaban plátanos utilizaron ampliamente el insecticida clordecona desde 1973 hasta 1993. La clordecona es un insecticida organoclorado remanente que se bioacumula fácilmente en los organismos. En 2009, realizamos un muestreo de *M. torquata* en Basse-Terre, Guadalupe, recorriendo 270 km a lo largo de 44 ríos para evaluar los efectos de la clordecona en la conducta de selección del hábitat. Durante nuestro muestreo tuvimos 47 avistamientos de esta especie, de los cuales, estimamos que eran 16 individuos diferentes. Un análisis de selección de hábitat reveló que estos individuos fueron encontrados principalmente en secciones de ríos que fluían a través de bosques ombrófilos, pero estaban ausentes en la costa del océano y en las partes bajas de los ríos. La distribución de *M. torquata* en Guadalupe podría estar asociada negativamente con áreas muy contaminadas por la clordecona. Proponemos que, el uso generalizado de clordecona en plantaciones de plátanos en Guadalupe tuvo consecuencias ecológicas adversas y puede ser responsable de la ausencia de *M. torquata* en los hábitats de las tierras bajas de la isla.

Palabras clave Antillas, bioindicador, clordecona, contaminación del suelo, *Megaceryle torquata*, selección de hábitat

Résumé Sélection de l'habitat par le Martin-pêcheur à ventre roux (*Megaceryle torquata stictipennis*) sur la Basse-Terre en Guadeloupe : potentielle relation négative avec la pollution au chlordécone • Dans les Petites Antilles, le Martin-pêcheur à ventre roux (*Megaceryle torquata stictipennis*) ne vit que sur trois îles : Martinique, Dominique et Guadeloupe. De 1973 à 1993, les cultivateurs de bananes de Martinique et de Guadeloupe ont utilisé de manière intensive un insecticide appelé chlordécone. Il s'agit d'un insecticide organochloré rémanent qui s'accumule facilement dans les organismes. En 2009, nous avons réalisé un recensement du Martin-pêcheur à ventre roux sur la Basse-Terre, en Guadeloupe, en parcourant 270 km le long de 44 cours d'eau afin d'évaluer les effets du chlordécone sur le comportement de sélection de l'habitat de l'espèce. Durant notre étude, nous avons rencontré 47 Martins-pêcheurs à ventre roux que nous estimons correspondre à 16 individus différents. Une analyse de la sélection de l'habitat montre que le Martin-pêcheur à ventre roux se trouvait principalement sur les sections de rivières traversant la forêt ombrophile et était absent des rivages océaniques et de la partie basse des cours d'eau. La répartition du Martin-pêcheur à ventre roux en Guadeloupe pourrait être négativement corrélée aux zones hautement polluées par le chlordécone. Nous suggérons que l'épandage massif de chlordécone dans les bananeraies de Guadeloupe a eu des conséquences écologiques néfastes et pourrait être responsable de l'absence du Martin-pêcheur à ventre roux dans les habitats de plaine de l'île.

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Mots clés Antilles, bioindicateur, chlordécone, Martin-pêcheur à ventre roux, *Megaceryle torquata*, pollution du sol, sélection de l'habitat

The Ringed Kingfisher (*Megaceryle torquata*) is a common and widely distributed species across Central and South America (Woodall 2001). In the Antilles, however, the presence of the species is heterogeneous among islands. For instance, the Ringed Kingfisher does not occur in the Greater Antilles, and in the Lesser Antilles, *M. t. stictipennis* is only found in Dominica, Martinique, and Guadeloupe (Remsen 1990), suggesting that favorable ecological conditions are only met on a few islands, or that anthropogenic activities could be limiting the Ringed Kingfisher distribution. Of particular interest for the distribution of many bird species are the agricultural practices known to affect various aspects of their biology and ecology (Geiger *et al.* 2010). Banana production in Guadeloupe, an important and intensive agricultural activity of many people living on tropical islands, has led to marked modifications of the landscape, such as widespread deforestation.

Banana farming is tightly associated with chlordecone, an organochlorine insecticide that was used heavily and extensively by farmers to control damage by a root borer, the banana weevil (*Cosmopolites sordidus*), from 1973 until its ban in Guadeloupe in September 1993 by French law (Cabidoche and Lesueur-Jannoyer 2011). The widespread use of chlordecone resulted in pervasive pollution of soils, waters, and riverbed sediments (Crabit *et al.* 2016), from which the ecological consequences remain poorly documented and studied in Guadeloupe. Since agricultural chemical use can potentially alter the distribution of birds (Douthwaite 1982, Parsons *et al.* 2010, Mineau and Whiteside 2013), one factor that may have influenced Ringed Kingfisher populations in Guadeloupe is the historical use of chlordecone.

Chlordecone is a long-lasting organic pollutant with carcinogenic, mutagenic, and reprotoxic consequences for exposed organisms. Previous studies have found strong negative effects of chlordecone on the reproductive biology of many wildlife species (Eroschenko 1981). In birds, chlordecone has bioaccumulated in the eggs of Osprey (*Pandion haliaetus*) living along a chlordecone-polluted river in the USA (Wiemeyer *et al.* 1988). Additionally, organochlorides such as chlordecone can damage the nervous system, altering the breeding behavior of seabirds (Burger and Gochfeld 2001). Organochlorides can negatively affect many aspects of bird biology, ranging from organism functioning and reproductive success to ecological processes such as population abundance and viability (Saaristo *et al.* 2018). For instance, dichlorodiphenyltrichloroethane (DDT) led to the decline of Brown Pelican (*Pelecanus occidentalis*) populations in California, USA, by causing the thinning of eggshells and ultimately reproductive failure (Risebrough *et al.* 1971).

Pesticides can impact ecosystems both directly and indirectly (Saaristo *et al.* 2018). Direct effects include those where pesticides act on the physiology of exposed organisms, altering the metabolism, cognitive ability, or behavior of individuals, and ultimately leading to reduced survival and reproduction. Indirect effects include those where pesticides have cascading effects on prey abundance or habitat quality, which indirectly impact reproduction and survival of individuals at higher trophic levels (Campbell *et al.* 1997). Indirect effects may also modify the behavior of individuals, such as by reducing predator avoidance, limiting predation efficiency, or decreasing movement ability, which all magnify the direct effects of contaminants on wildlife populations (Saaristo *et al.* 2018). Positioned at the top of the aquatic food chain, kingfishers may be particularly susceptible to bioaccumulation of contaminants in body tissues (Clarkson 1995). Accordingly, many kingfisher species are used as biomonitors of waterways polluted by various contaminants, including mercury (Zamani-Ahmadmahmoodi *et al.* 2009, White and Cristol 2014) and organochlorides such as DDT (Tanabe *et al.* 1998, Evans and Bouwman 2000). Given reported adverse effects of many organochlorine compounds on the life histories of birds, especially fish-eating birds (Moore 1965, USEPA 1975, Schäfer *et al.* 2011), the historical use of chlordecone may explain the distribution and habitat selection of Ringed Kingfishers in Guadeloupe.

Here, we investigated whether chlordecone pollution could be related to Ringed Kingfisher habitat selection in Guadeloupe. We conducted presence-absence surveys for this species along 44 rivers located on Basse-Terre, Guadeloupe, and calculated selection ratios to determine whether Ringed Kingfishers avoid polluted areas. If chlordecone negatively affects the abundance of Ringed Kingfishers, we would expect to find proportionally fewer individuals in polluted habitats compared with its availability in the landscape (Manly *et al.* 2007). To lend further support to the potential negative association between chlordecone pollution and Ringed Kingfisher habitat selection, we accounted for ecological variables that could potentially confound the effect of chlordecone, including those that capture the main spatial structure of Basse-Terre in terms of available habitats and river characteristics.

Methods

We carried out our study in Guadeloupe, an archipelago of the Lesser Antilles in the Caribbean Sea. On Basse-Terre (848 km², 16°10'N, 61°40'W), a mountain range runs from north to south, spanning between 500–800 m above sea level. The highest point is the 1,467-m summit of the southern volcano, La Soufrière. The mountain range blocks the prevailing easterly winds from the Atlantic Ocean, causing the east coast of Basse-Terre to be wetter than the leeward west coast. Two main forest types lie along the elevation gradient of the volcano (Van Laere *et al.* 2016). At low elevation lies the lower rainforest dominated by *Amanoa caribaea*, *Tapura latifolia*, and *Dacryodes excelsa* trees. At higher elevation, the rainforest is mostly dominated by *Richeria grandis*. Many rivers run from the mountain range to the ocean, especially along the wetter east coast (Fig. 1 b). We sampled 21 rivers on the windward east coast and 23 rivers on the leeward west coast. The rivers varied in length, with 14 rivers less than 5 km, 15 between 5 and 10 km, 13 between 10 and 25 km, and the two longest rivers longer than 25 km. For the 42 shorter rivers (those < 25 km), we selected rivers that were equally spread around Basse-Terre and had different levels of chlordecone pollution (Fig. 1 a).

We conducted surveys of Ringed Kingfishers from 20 March to 20 August 2009. To obtain a baseline for the species' habitat use, we first studied the behavior of one pair, observing the birds for 33.5 hr over 4 days (20, 23, 24, and 26 March 2009). We then surveyed Ringed Kingfishers using two methods: by kayak, where possible in the lower sections of rivers, and by walking along rivers. We assessed the Ringed Kingfisher presence on a river section by moving upstream slowly along the riverbed at a speed of 0.8 km/hr (1 km/hr with a kayak) starting at sunrise. We sampled each river only once and usually walked back to the coast away from the rivers afterwards. During the surveys, we searched for birds in the riverbed vegetation, using Swarovski 10×25 binoculars to spot any perched kingfishers. We recorded the GPS location of any Ringed Kingfisher heard or seen. During the surveys, we watched and listened for Ringed Kingfishers carefully and thus were confident we did not miss any birds. We sometimes made repeated observations of a single individual because some birds flew ahead of us as we surveyed rivers. We always recorded the locations where Ringed Kingfishers were initially flushed. If the bird flew upstream, we also recorded the subsequent perch locations. We visually tracked each flying bird until it reached its territory limit and turned back. We used this behavior to differentiate individual Ringed Kingfishers, with any new bird flushed upstream considered to be a different individual. However, because birds were not individually identified by a band, which presented a risk of confounding several individuals, the number of different Ringed Kingfishers we observed was prone to errors. Because of the uncertainty in each bird's identity, we used all of our observations in our analyses. We also acknowledge that birds may use different habitats during early spring and summer, which could affect our results.

Between 2013 and 2017, after we had conducted our study, birdwatchers recorded new, opportunistic Ringed Kingfisher observations on the Karunati database (accessed on 10 May 2019). We retrieved the observation locations reported by the observers from the Karunati database to reinforce our own observations and increase our sample size for our statistical analyses. We hence assumed each observation represented a different Ringed Kingfisher, a likely met assumption given the relatively large distance between the different observations (mean = 7.1 km, range = 2.2–12.2). During our surveys, we also made anecdotal observations of adult Ringed Kingfishers bringing prey to their chicks and identified the prey species.

We described the local environmental conditions of the Ringed Kingfisher habitat along the sampled rivers with four ecological variables. Using QGIS (QGIS Development Team 2019), we first created 250-m long river segments, starting from the river mouth and extending toward its spring. For each segment, we used a digital elevation model to calculate: (1) the height difference in degree ("slope") between the start and the end of the river segment, which is associated with the speed, depth, and turbidity of the waters and thus is likely associated with the fishing conditions for the birds; (2) the average elevation (m) of the 250-m long river segment ("elevation"), as this accounts for the elevational gradient in plant composition, land use by farmers, and other human activities, because at high elevations the rainforest remains dominant, while at lower elevations forests were often cleared for banana and crop plantations, particularly on the east coast; (3) the bearing in degrees ("angle"), as this accounts for the contrasting ecosystems between the windward and leeward coasts. Ombrophilous forest is generally found on both coasts, while seasonal evergreen and semi-deciduous forest are found only on the west coast (Van Laere *et al.* 2016). Finally, we added (4) the chlordecone pollution level according to the classification and map of land pollution risks by Rochette *et al.* (2017). Rochette *et al.* (2017) assessed soil pollution using a multiresidue analysis of pesticides in 227 soil samples taken from randomly chosen rivers in Guadeloupe as well as 120 soil samples collected from the estuary of 59 different watersheds. They then interpolated this data using a Kriging procedure to produce a map of chlordecone pollution risks (Rochette *et al.* 2017). Class 5 soils have "very high risk" of chlordecone pollution (> 90%) and cover 4,761 ha (5.6%) of Basse-Terre; Class 4 soils have "high risk" of chlordecone pollution (~80%) and cover 1,629 ha (1.9%); Class 3 soils have "low risk" of pollution (~30%) and cover 181 ha (0.2%); Class 2 soils have "low to negligible risk" of chlordecone pollution (< 10%) and cover 27,929 ha (32.9%); and Class 1 soils have "no pollution by chlordecone", representing the remaining 59.3% of Basse-Terre. We assessed the pollution risk of each river segment ("chlordecone") by assigning it the highest pollution risk class of all contiguous areas.

To assess whether Ringed Kingfishers avoided polluted areas, we calculated selection ratios (SR), a classical measure of preference and avoidance in habitat selection studies (Manly *et al.* 2007). We calculated SRs by dividing the proportional use of a given habitat by the proportional availability of that habitat. A SR value of one means that birds use the focal habitat randomly (i.e., use is equal to availability). When individuals avoid a particular area, habitat is used to a lower extent than its availability and the SR will be < 1. Conversely, a preferred habitat will have a SR > 1. Note that habitat preference and avoidance are the standard terms used in habitat selection studies and describe an observed pattern that can be the result of many different behaviors and factors—for example, the active avoidance of a threat or the absence of a species in a certain habitat due to a lack of suitable resources. For all sampled river segments, we calculated the proportion of the river falling into each of the five chlordecone pollution risk classes. We repeated this calculation for the subset of river segments where we observed Ringed Kingfishers. We then calculated selection ratios for each pollution class by dividing the proportion of river segments with Ringed Kingfisher observations in a given pollution class by the proportion of all river segments in that class. We computed the variance for each SR according to the method described in Aho and Bowyer (2015) for the variance of the two ratios.

We complemented the selection ratio analysis of Ringed Kingfishers with a multivariate approach called MADIFA (Mahalanobis Distance Factorial Analysis; Calenge *et al.* 2008). For this, we first conducted a principal component analysis on the environmental descriptors to uncover the most influential variables structuring the landscape. This multivariate description of the environment

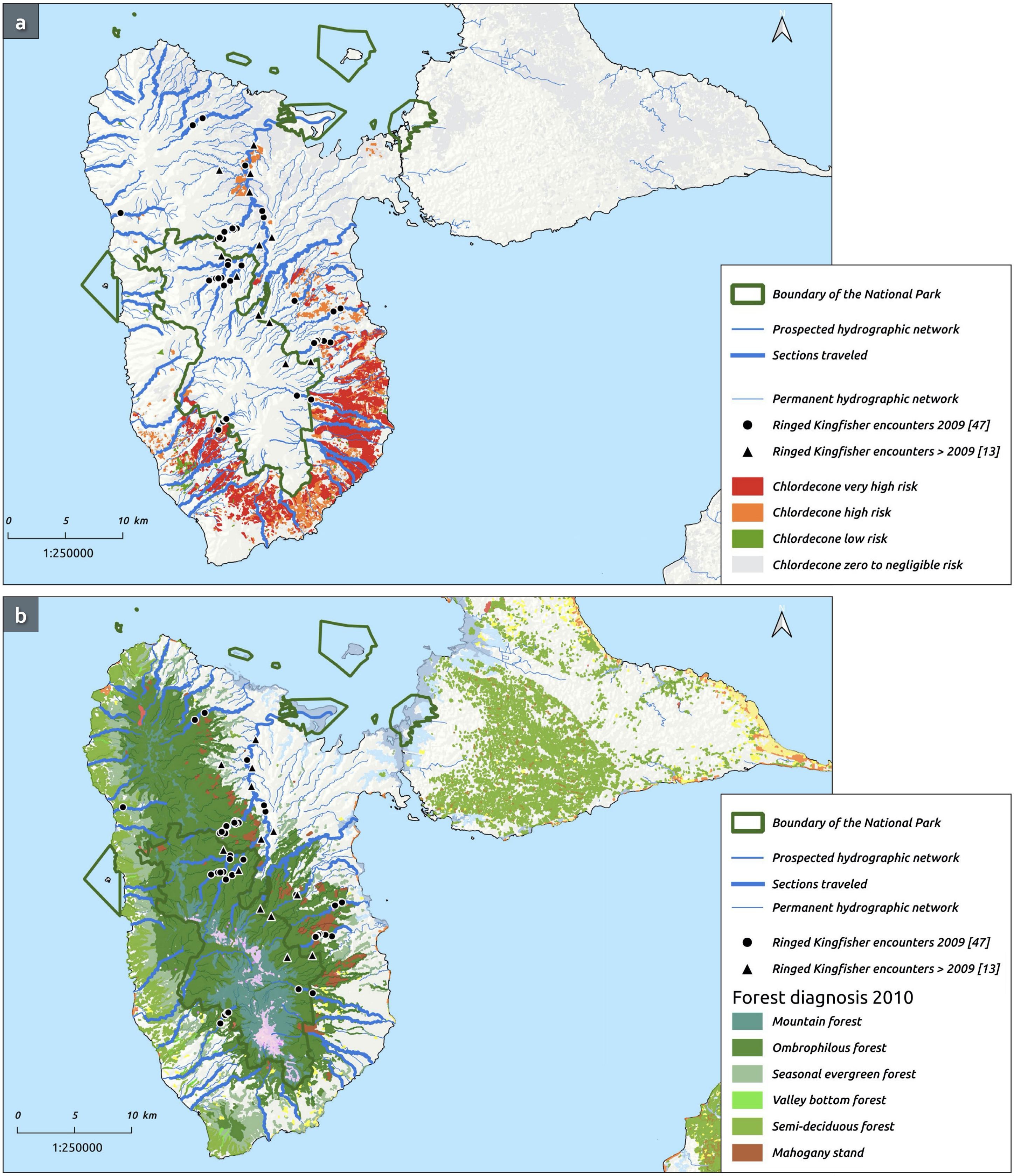

Fig. 1. Location of Ringed Kingfisher (*Megaceryle torquata stictipennis*) encounters (2009–2017) on Basse-Terre, Guadeloupe. In total, we recorded 47 observations of Ringed Kingfishers, though the number of different birds remains uncertain as some individuals might have been seen several times if disturbed by the observer. A gross estimate of the number of different birds we detected is 16. We plotted the observation locations on the map of (a) chlordecone exposure risk and (b) forest habitats. Source for maps: BDTOPO—Institut Géographique National Paris; SRTM—DAAF Guadeloupe).

corresponds to the ecological space available to the birds. Then, the MADIFA compares where birds are present and absent in the multivariate ecological space defined above. If birds select the habitat along some variables, the locations where birds were detected should be associated with one or several axes. An advantage of the MADIFA method over the selection ratios (Manly *et al.* 2007) is that it visualizes and accounts for spatial covariation among the different environmental descriptors in our study. As a side note, none of the methods could account for potential pseudo-replication in the data arising from the repeated observations of the same individuals. We hence treated each observation as an independent record and assumed little or no effect of pseudo-replication on our results. We ran all analyses using R 3.5 (R Core Team 2019) and the associated packages asbio (Aho 2019) and adehabitatHS (Calenge 2006).

Results

We surveyed 270 km of river habitat over a period of 376.6 hr (93.8% of the habitat by foot and 6.2% by kayak). On Basse-Terre the total length of rivers with permanent water was 1,012 km. Thus, we surveyed 68% of the total length (395 km) of the 44 rivers we sampled on Basse-Terre, representing 27% of the total length of permanent rivers on the island that were available to Ringed Kingfishers. During our surveys, we never observed Ringed Kingfishers on rivers shorter than 5 km, which represent 46 km of the 395 km we sampled. This suggests that Ringed Kingfishers may need longer rivers to sustain their needs. Thus, we removed rivers shorter than 2 km (113 km out of the 1,012 km on Basse-Terre) from our analysis, as we believe these short rivers would not support a Ringed Kingfisher. After excluding these rivers, our final analysis consisted of 899 km of river habitat available to Ringed Kingfishers (including 395 km of the 44 rivers sampled), split into 1,068 segments.

We recorded a total of 47 Ringed Kingfisher locations. From these observations, we tentatively assessed the number of different individuals to be 16: 12 singletons and 2 couples. After completing our study, 13 new Ringed Kingfisher observations were recorded by birdwatchers between 2013 and 2017 (Fig. 1 a). These additional locations aligned with our observation that Ringed Kingfisher avoid polluted river segments (Fig. 1 a).

We overlaid the data on Ringed Kingfisher distribution with the map of chlordecone contamination risk (Fig. 1 a) and forest habitat (Fig. 1 b). Our results suggest that Ringed Kingfishers are found (1) outside of high chlordecone contamination areas (> 80% polluted, Classes 4 and 5 of chlordecone contamination risk) and (2) mostly in the ombrophilous forest. Our statistical analysis of habitat selection confirmed our visual inspection of Ringed Kingfisher locations on the map. River segments with no chlordecone were used slightly more relative to their availability ($SR_1 = 1.18 \pm 0.01$; Fig. 2). Conversely, Ringed Kingfishers used river segments with any risk of chlordecone pollution (contamination risk Classes 2–5) significantly less relative to their availability ($SR_{2-5} = 0.46 \pm 0.30$, $p = 0.07$). Ecologically speaking, this means that the odds of finding a Ringed Kingfisher are 2.56 times higher in unpolluted compared to polluted river segments on Basse-Terre, on average. When considering each pollution level separately, all estimates of selection ratios for polluted river segments were < 1, although not statistically different from 1 (Fig. 2; $SR_2 = 0.32 \pm 0.98$; $SR_3 = 0.00 \pm 2.15$; $SR_4 = 0.00 \pm 2.08$; $SR_5 = 0.90 \pm 0.50$).

The multivariate habitat selection analyses lend further support to the selection ratio results. The correlation circle (Fig. 3 a) showed that elevation and bearing correlated positively because high elevation areas are found mostly in the southwest of the island. Importantly, the level of chlordecone pollution was orthogonal to the other environmental variables, suggesting that the pollutant in the landscape was statistically independent of the other landscape variables used to describe the Ringed Kingfisher environment. This also means that any effect of chlordecone on Ringed Kingfisher habitat selection is likely not due to potential confounding by the described landscape structure. When projecting the points on the first two axes of the ecological space, the MADIFA shows that Ringed Kingfishers (black dots, Fig. 3 b) selected high elevation river segments rather than low elevation segments. Similarly, river segments with steep slopes were used less intensively than flatter ones. Furthermore, none of the river segments where birds were seen are in the lower-left quarter of the plot, which represents the eco-

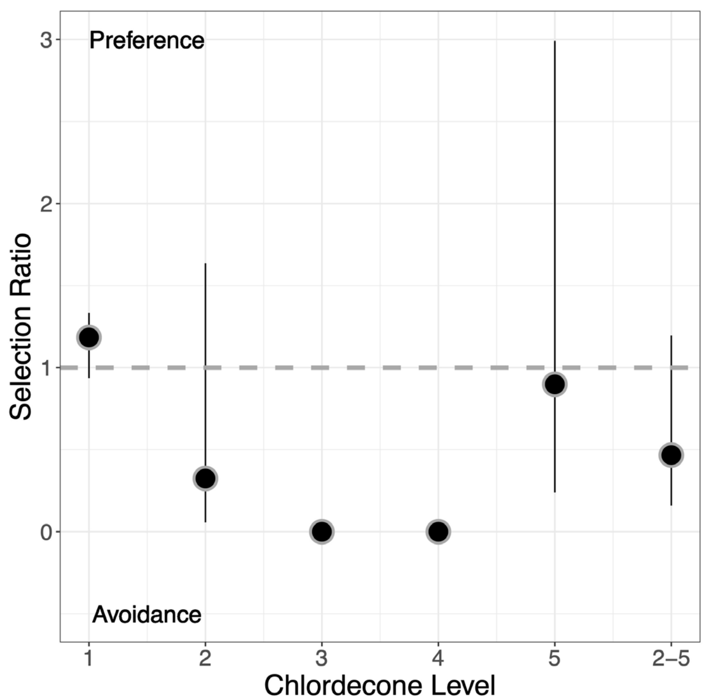

Fig. 2. Selection ratios (with associated 95% confidence intervals) based on Ringed Kingfisher observations made along river segments with five different levels of chlordecone pollution on Basse-Terre, Guadeloupe between 2009 and 2017 ($n = 47$ bird locations and approximately 16 different individuals). Chlordecone levels from 1–5 indicate an increasing risk of finding polluted river segments, and the last category pooled all polluted segments (levels 2–5). Although selection ratios are not statistically different from 1, Ringed Kingfishers seem to use non-polluted segments of rivers (chlordecone level 1) more relative to availability, contrasting with river segments with low to high levels of pollution (chlordecone level 2–5), which are used less relative to availability.

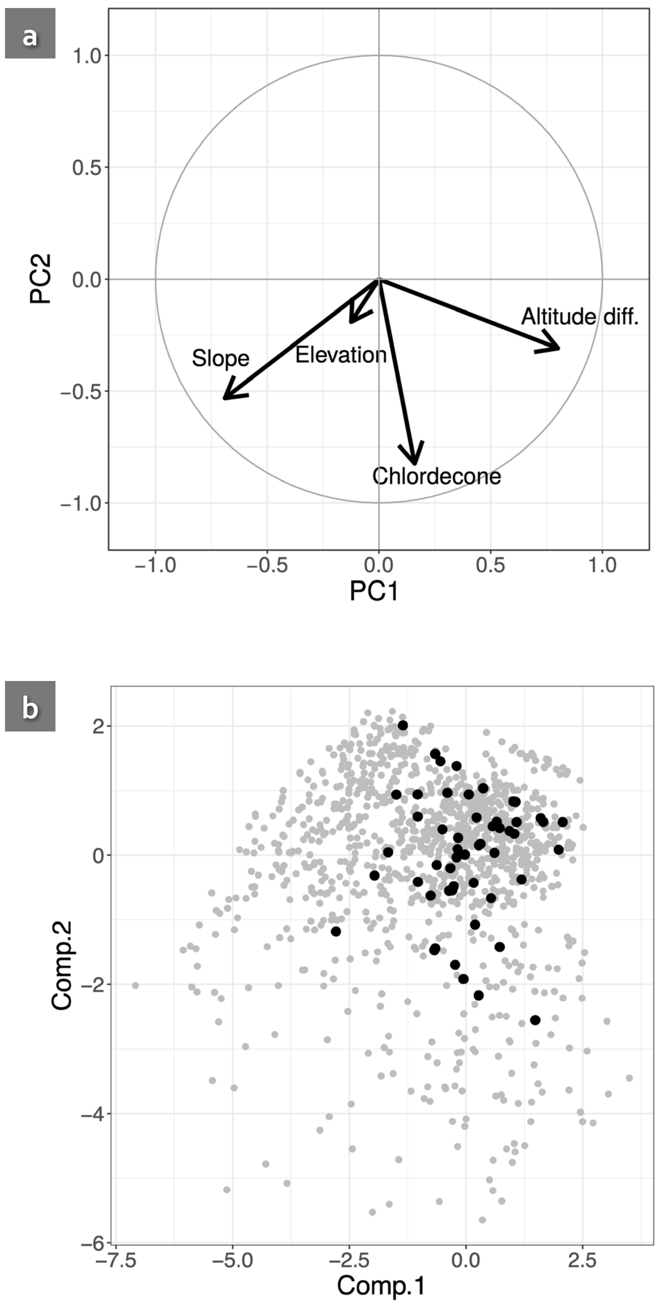

Fig. 3. Graphical output of the MADIFA displaying the ecological conditions prevailing in river segments where we observed Ringed Kingfishers (black dots) compared to available river segments (gray dots) on Basse-Terre, Guadeloupe, between 2009 and 2017 (*n* = 47 bird locations from approximately 16 different individuals). We used four variables to describe the environmental conditions along each of the 250 long river segments: the average height difference in degree ("Altitude diff."), the average elevation in m ("Elevation"), the bearing in degrees ("Slope"), and the chlordecone pollution level ("Chlordecone"). (a) Correlation circle of the principal component analysis of the river segment characteristics showing that chlordecone pollution is only weakly associated with the other environmental descriptors we used; (b) the MADIFA shows that none of the river segments where birds were seen were found on the lower-left quarter of the plot (black dots), which represents the ecological space with low to high chlordecone pollution.

logical space with chlordecone pollution (black dots, Fig. 3 b). Coupled with the selection ratios, this multivariate analysis is congruent with the idea that in Guadeloupe, Ringed Kingfishers may use river segments polluted by chlordecone less than their availability.

Discussion

Given the particular agricultural history of some islands in the Antilles, we hypothesize that the long-lasting effects of chlordecone pollution—a compound that persists in the environment for centuries (Crabit *et al.* 2016)—could have had adverse ecological consequences for freshwater ecosystems in Guadeloupe, including for the Ringed Kingfisher. On Basse-Terre, we document a lower relative use of the lower sections of rivers by the Ringed Kingfisher, which run through a heavily chlordecone-contaminated estuary on the east coast (Fig. 1). A study on the White-throated Dipper (*Cinclus cinclus*) found a similar absence of this river-dwelling species in 93.7% of polluted or strongly polluted streams in Italy (Sorace *et al.* 2002). Thus, chlordecone pollution may partially explain the past and current distribution of Ringed Kingfishers on Basse-Terre (Fig. 1 a). In the 1970s, Ringed Kingfishers were regularly recorded in Sofaïa, Capesterre, and Trois-Rivières, Basse-Terre (Pinchon 1976); however, 40 years later, we detected the species only in the first two locations, and only in upstream areas. One possible explanation for this difference is that chlordecone has not been spread by banana farmers in upstream areas. Overall, the Ringed Kingfisher is not found in the lower parts of rivers or the ocean front on Basse-Terre (Fig. 1). This could be related to the 84.1% of watersheds analyzed having pesticides such as chlordecone (Rochette *et al.* 2017). Additionally, during the 10 years following our survey, all sightings of Ringed Kingfishers by birdwatchers in Guadeloupe were made outside of areas with high chlordecone pollution risk. Although we detected four Ringed Kingfishers in polluted areas (Class 4 and 5), they were all found in areas where land pollution was patchily distributed, allowing them some access to unpolluted areas as well.

The spatial avoidance of polluted river segments by the Ringed Kingfisher could result from direct and indirect effects of chlordecone on the birds. Direct effects usually include the death of individuals or regular reproduction failures because of organism dysfunction when exposed to chemical pollutants (Saaristo *et al.* 2018). During our surveys, we observed the feeding of Ringed Kingfisher chicks with basket shrimp (*Atya innocous*), stream shrimp (*Macrobrachium crenulatum*), and the river goby (*Awaous banana)*. An ecotoxicology study carried out on southern Basse-Terre rivers found substantial amounts of chlordecone in these three prey species (Coat *et al.* 2011). Although we currently lack published material on the Ringed Kingfisher diet in the tropics to strengthen this observation, we can expect a direct effect of chlordecone on birds through bioaccumulation in tissue from polluted food resources in the lowlands of Guadeloupe. Clearly, an epidemiological study on the Ringed Kingfisher is needed to understand the effects of chlordecone on the species' physiology and life history. Moreover, indirect effects of chlordecone may proceed from cascading effects of contamination on prey species community or population size and, in turn, may lower the suitability of habitat for predators by limiting food resources

(Saaristo *et al.* 2018). Without bird banding, we cannot assess whether kingfishers move from one river to another to actively avoid chlordecone pollution, but over time, we believe that both direct and indirect effects of chlordecone may have led to the absence of individuals from polluted areas, as we suggest is the case in Guadeloupe.

Our results indicate that other ecological factors might also be related to the distribution of the Ringed Kingfisher in Guadeloupe. For example, Ringed Kingfishers used river segments located on the eastern coast more than expected based on their availability (Fig. 3), and we observed the Ringed Kingfisher most on the windward east coast (Fig. 1 b) where ombrophilous forests grow. Rivers running through this type of forest are long with gentle slopes and have riverbanks that offer many clay cliffs for nesting. In this ecosystem, food resources are likely available to Ringed Kingfishers given the many schools of fishes we saw while walking the rivers. The vegetation structure of the forest also provides numerous perches ideal for birds to fish. The ombrophilous forest hence appears to be a favorable habitat for the Ringed Kingfisher due to both food resources and nest-site availability (Woodall 2001). Conversely, on the dryer leeward west coast, fish abundance is lower and rocks make up most of the riverbanks. On average, rivers are also shorter (1.8 km vs. 3.0 km) and steeper (16.6° vs. 11.0°) hence creating more rapid water streams. In general, the west coast habitat seems less favorable to Ringed Kingfishers compared to the east coast because of the river characteristics, limited food resources, and the lack of soft banks for nesting, forcing birds to fly far from rivers to dig their burrow nests (Woodall 2001). Accordingly, we detected only two individuals on the west coast. One individual was living in the northwest (Fig. 2), which we associated with the presence of a fish farm where it was seen fishing regularly.

Elevation is another influential ecological variable of Ringed Kingfisher habitat selection. Here, elevation likely serves as a proxy of river physical characteristics, as water speed, depth, temperature, and turbidity all vary gradually from the high elevation river source to the low elevation estuary (Allan 1995). It is known that Ringed Kingfishers need fairly deep water to dive and should hence be most abundant in the lowlands where rivers are deepest (Skutch 1972). In our study, we found the opposite pattern and attribute this difference to a combination of chlordecone pollution and unsuitable habitats for Ringed Kingfishers. On Basse-Terre, although chlordecone pollution of soils and waters decreases with altitude (Fig. 1), our analysis found a weak spatial correlation between the two variables at the landscape level (Fig. 3 a). In our multivariate analysis, we deciphered the independent effects of chlordecone pollution risk and elevation on habitat selection and found that Ringed Kingfishers were present relatively less in polluted river segments and in those located at low elevation (Fig. 3 b). The avoidance of unpolluted lowland river segments may be explained by the marked human footprints on the beds, banks, and surroundings of rivers in Guadeloupe. For instance, the riverbed of the river flowing through the city of Basse-Terre is made of mostly concrete, which probably reduces fish abundance drastically. Similarly, in banana plantations, the forest is sometimes cleared down to the river's edge, except for a narrow strip of trees along riverbanks, modifying the vegetation structure and density. These strips of trees likely provide the necessary perches for Ringed Kingfishers, and thus a lack of perches cannot explain their low relative abundance in banana plantations. The lowlands of Guadeloupe islands are at the heart of human activities, which generate all kinds of perturbations for wildlife and possibly for the Ringed Kingfisher. Light pollution, chlordecone upstream pollution, active disturbance, presence of predators, and competition for food with fishermen could all contribute to deterring Ringed Kingfishers from lowland rivers segments.

Our study suggests that the Ringed Kingfisher could be a useful bioindicator of areas with organochlorine pollution, specifically chlordecone contamination. While our habitat selection analysis lacks statistical power and is potentially affected by repeated observations of the same birds (i.e., pseudo-replication; Machlis *et al.* 1985), given the potentially dramatic consequences for the Ringed Kingfisher, the low level of statistical significance due to low sample sizes should not hamper the biological signal of our results (Yoccoz 1991). Although we cannot prove the generalized ecological effects of chlordecone in the Antilles, we suggest that historical chlordecone use by banana farmers could have had and may still be having an ongoing influence on Ringed Kingfisher populations and distribution on certain islands, including Guadeloupe. To further explore this potential issue, researchers should collect data on the ecology of the Ringed Kingfisher with detailed descriptions of diet throughout the year, habitat, territory size, and behavior, and should also investigate the ecological consequences of chlordecone pollution on individuals, populations, and avian communities.

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Title Page Illustration

Male Ringed Kingfisher (*Megaceryle torquata stictipennis*) with prey (river goby, *Awaous banana*), photographed by Pascal Villard on 3 June 2009 on Basse-Terre, Guadeloupe.

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