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Effect of introduced species and habitat alteration on the occurrence and distribution of euryhaline fishes in fresh- and brackish-water habitats on Aruba, Bonaire and Curaçao (South Caribbean)

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Key words: fish assemblages, semi-arid islands, intermittent rivers, aquatic refugia, ecological integrity

Abstract

We conducted an ichthyological survey during the dry season of 2006 on the semi-arid islands of Aruba, Bonaire and Curaçao to provide information on species composition, richness and distribution in natural and non-natural aquatic habitats. The dry season species assemblages (N = 9 species) comprised less species than the wet seasons, and these data refine our knowledge of the indigenous fish fauna and its refuge localities during phases of drought and ensuing high salinity. A hierarchical cluster analysis reveals that the three islands have different species compositions with Curaçao being the most diverse, probably due to its having the most habitats and freshwaters present throughout the year. Species richness was unrelated to salinity and species diversity was highest in canalised streams. In the dry season fewer amphidromous species are present than in the wet season. We found no significant effect of human-induced changes on the presence or absence of fish species in the Netherlands Antilles. The presence of exotic species (including *Xiphophorus helleri* on Aruba, a first record for this island, and *Oreochromis mossambicus* and *Poecilia reticulata* occurring on all three islands) did not have a clear effect on the presence of indigenous species, nor did human alteration of the habitats have an influence on the occurrence of fish species.

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Introduction

Inland population of fishes in arid regions frequently disappear through the dry season only to restock their former distribution ranges in wetter times by populations that live in coastal, marine waters (Feltkamp and Kristensen, 1970; Lundkvist, 2005). These populations may need the inland trek to meet certain requirements of their amphidromous life cycle. Dwindling habitats will see a deterioration of that mechanism and bring down the species diversity in these arid regions.

Processes, other than normal seasonal droughts, that can influence the ecological integrity of aquatic communities are the introduction of foreign species, habitat alteration, environmental pollution, erosion by logging, and climate change amongst others (Van Buurt, 1999; Godinho and Ferreira, 2000). More so on (small) islands than on the mainland, these processes may lead to the extinction of fish populations (Lelek, 1987).

To explore the effects of such disturbances we studied the distribution of indigenous fish species in the dry season in a series of small arid islands in the Caribbean. We specifically addressed the effects of periods of drought and rising salinity on the fish fauna, and categorized the habitats used by these species to survive the seasonal declines of populations. We selected the islands of the Leeward group of the Netherlands Antilles in the Caribbean because its aquatic biodiversity is well-known as a result of a series of comprehensive studies (Stephensen, 1933; De Beaufort, 1940; Feltkamp and Kristensen, 1970; Debrot, 2003). The ephemeral nature of several inland water reservoirs on these semi-arid islands sets barriers to a thorough inventory of species. Levels of aqua- and agriculture and urbanization differ among the islands, affecting occurrence of species. The island of Aruba is close enough to mainland Venezuela

to have been influenced by faunal invasions during the Late-Pleistocene glaciation (Van Buurt, 2005) but the other islands are separated from the mainland by the Bonaire Trench precluding such faunal exchanges. These different histories may influence differences in the ichthyofauna on the three islands, as well as the ability of these species assemblages to withstand human-induced changes to their environment.

In an earlier study Debrot (2003b) reported on the general occurrence of euryhaline fishes in freshwater habitats during the wet season and in exceptionally wet conditions during part of the dry season on especially Curaçao, based on original field research and on the holdings of the fish collection of the Zoological Museum Amsterdam. Here we further this study, by assessing the inland fish species composition at the height of the dry season on Aruba, Bonaire and Curaçao, to assess the effects of human-induced changes (including the introduction of exotic fish species) on these islands' ichthyofauna.

Materials and methods

Study area

The island group of Aruba, Bonaire and Curaçao lies in the southern Caribbean. With its 193 km² being the smallest island of the three, Aruba lies 77 km west of Curaçao and 27 km north of Venezuela and has an annual mean temperature of 27°C. Bonaire, located 40 km

eastward of Curaçao, has a surface area of 246 km² and an annual mean temperature of 28°C, the annual rainfall 463 mm. Curaçao lies approximately 70 km off the coast of Venezuela. The total surface area is approximately 444 km², the annual mean temperature is 27.5°C and annual rainfall averages 566 mm. On all three islands, approximately 50% of the annual rainfall (Aruba 408 mm, Bonaire 463 mm, Curaçao 566 mm) occurs in October-December, while May, June and July are the driest months. The islands are without true rivers, but are traversed by seasonal, intermittent streams. Other water is in a large number of agricultural water catchment dams, most of which were constructed during the colonial era, and which are continued to be maintained (Debrot 2003a). In addition, freshwater ponds are present at golf courses and wastewater treatment plants, significantly increasing the year-round availability of freshwater (Prins *et al.*, 2005; Prins and Nijman, 2005; Nijman *et al.*, 2008).

In 2000, continued heavy rainfall during the first quarter of the year caused streams and reservoirs (dams), which normally would be dry by February, to carry water well into June of 2000, the period of sampling for Debrot (2003a), and thus resembled wet season circumstances. The sampling period used in this study (July 2006) coincided with normal drought conditions; many of the streams and some of the dams had dried completely. We categorized the several habitats in Table 1.

In July 2006 on Aruba, no streams or small rivers were flowing and fish were sampled in man-made lakes

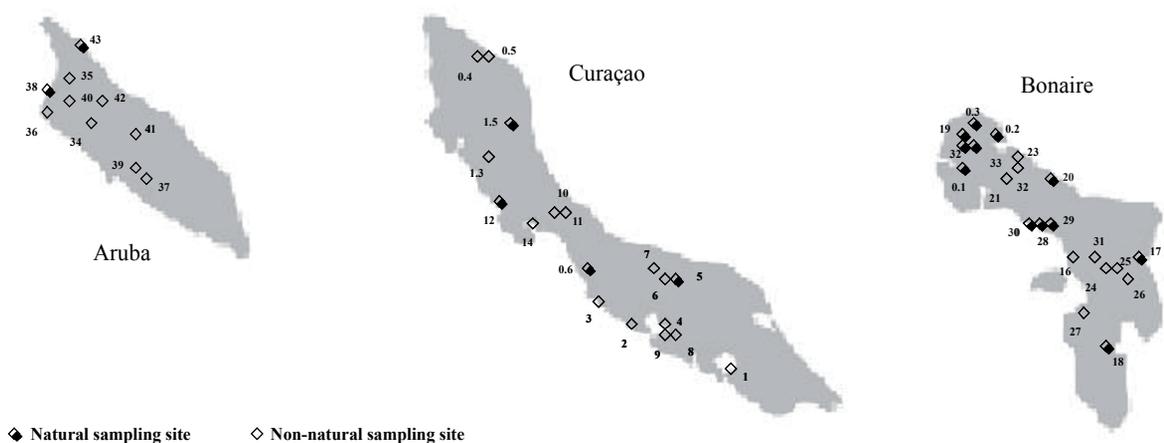


Figure 1. Map of the Caribbean islands of Aruba, Curaçao and Bonaire, Netherlands Antilles, with sampling sites visited in 2006 (distances between the islands not to scale). Non-natural sampling site refers to water bodies that are semi-natural (altered by making concrete streambed floors or walled sides to a stream) or dug ponds; natural sampling sites are water bodies that are not or only to a limited extent modified.

Table 1. List of sampling sites. A = Aruba, B = Bonaire, C = Curaçao. - = no data available. Stations 0.1, 0.2, and 0.3 were sampled in January 2006, all others in July 2006.

Island code	Site number	Name	Coordinates °N	°W	Altitude ft	Salinity mS/cm	Waterbody standing flowing 0 flowing 1	BasinType Natural 0 Adjusted 1 Man-made 2	Max Size of basin m ²	Watersurface while sampling m ²
B	0.1	Rooi Tambu WS	12 16'35	68 21'16	9	9.47	1	0	700	500
B	0.2	Kibrachacha	12 10'27	68 16'29	9	15.32	1	0	150	2000
B	0.3	Rooi Seru Pretu WS	12 17'13	68 22'48	90	7.15	1	0	240	45
C	0.4	Christoffelpark 1	12 21'13.20	69 06'11.95	29	-	0	1	375	375
C	0.5	Christoffelpark 2	12 21'10.46	69 06'16.33	30	-	0	1	150	80
C	0.6	Malpais	12 09'56.99	69 59'54.11	25	-	0	1	1400	600
C	1	Jan Thiel Mangrove	12 05'23.96	68 50'23.96	15	8.31	0	1	80	80
C	2	Coney Island	12 06'34.78	68 56'50.11	3	7.40	0	1	11700	11700
C	3	Golf 'BlueBay' lakes	12 18'24.04	68 58'54.78	31	1.32	0	2	7000	7000
C	4	SFT Bank kanaal	12 07'30.00	68 53'45.00	-	2.92	1	2	500	500
C	5	Muizenberg	12 19'29.50	68 55'06.03	71	6.29	0	0	154000	20000
C	6	Kaya Muizenberg	12 09'35.71	68 55'30.27	85	15.56	0	2	200	20
C	7	Sera Fortuna	12 06'59.12	68 55'50.11	96	5.58	0	1	13500	9000
C	8	Kaya Panacea	12 06'30.00	68 53'45.00	-	2.49	1	2	15	15
C	9	Bloempot	12 07'30.00	68 53'45.00	-	2.66	1	1	15	15
C	10	Landhuis Daniel 1	12 12'42.45	69 01'17.42	234	34.50	0	1	700	500
C	11	Landhuis Daniel 2	12 12'40.60	69 01'15.94	234	56.70	0	1	625	400
C	12	Daarbootbaai	12 12'55.07	69 04'44.08	19	101.4	0	0	131250	45000
C	13	San Juan lake	12 15'34.90	69 05'39.86	99	1.72	0	1	375	375
C	14	Jan Kok pool	12 12'47.62	69 03'11.68	19	3.63	0	2	18	18
C	15	Hofi Pastor	12 17'28.78	69 04'23.53	77	-	0	0	45	45
B	16	Kaya Papa Cornes	12 09'41.32	68 16'21.41	15	0.94	0	2	900	625
B	17	Washikemba	12 10'53.68	68 13'12.34	7	100.5	0	0	70000	10000
B	18	Sorobon windmill	12 05'22.77	68 14'33.76	14	-	1	1	360	360
B	19	WS Park stream	12 17'50.33	68 23'23.14	107	-	1	0	4	4
B	20	Boca Onima	12 15'02.71	68 18'42.61	37	-	0	2	125000	0
B	21	Windmill Rincon	12 14'56.62	68 20'55.31	144	-	0	1	1200	40
B	22	Benesuela	12 16'09.57	68 20'33.49	36	-	0	2	17500	17500
B	23	Donkey lake	12 15'25.75	68 20'14.34	35	-	0	2	800	800
B	24	Kaya Nikiboko 1	12 09'11.34	68 14'37.33	66	-	0	2	2500	400
B	25	Kaya Nikiboko 2	12 09'04.73	68 14'01.27	60	-	0	2	3300	400
B	26	Excavation lake	12 08'42.26	68 14'02.31	50	-	0	2	3900	1200
B	27	Hato cave	12 07'42.52	68 16'20.88	21	-	0	0	35	35
B	28	Stinapa cave 1	12 12'05.43	68 18'13.16	144	-	0	0	0	0
B	29	Stinapa cave 2	12 12'06.49	68 18'27.56	113	-	0	0	8	8
B	30	Karpata cave	12 12'14.93	68 18'32.47	60	-	0	0	100	100
B	31	LVV pond	12 09'38.99	68 15'17.38	51	-	0	2	35	35
B	32	Pos Mangel	12 17'44.97	68 23'25.16	80	-	0	0	9	6
B	33	Put Bronswinkel	12 17'47.43	68 23'20.85	141	-	1	0	16	16
A	34	Tanki Leendert	12 32'05.84	70 01'23.08	62	0.68	0	2	5600	5600
A	35	Lake Noord	12 33'46.22	70 01'40.46	36	0.89	0	2	10400	10000
A	36	Golfcourse 'The Links'	12 32'23.77	70 03'21.58	12	49.2	1	2	17500	17500
A	37	Rooi Bosal	12 29'41.26	69 58'44.80	85	0.27	0	2	4900	2000
A	38	Bird Sanctuary	12 33'19.80	70 03'11.41	17	1.9	0	1	250000	250000
A	39	Tanki Sabana	12 29'53.43	69 59'06.37	84	1.52	0	2	3750	1200
A	40	Tanki Flip	12 32'55.55	70 01'57.94	45	0.32	0	2	8625	4125
A	41	Cashero	12 31'24.24	69 59'08.96	105	0.43	0	2	9900	6000
A	42	Salina	12 32'55.12	70 00'50.38	89	9.47	0	2	36000	36000
A	43	Sero Pela	12 35'18.04	70 01'20.39	34	1.2	0	1	3850	3500

and ponds (Table 1). Only Bubali Bird Sanctuary (site 38, Figure 1) and Sero Pela (site 43) represent more or less natural conditions, the first being a large shallow swamp filled with purified sewage water (Lundkvist 2005), the latter a small, remote lake. On Bonaire, two sites were saline lagoons (site 17 and 18), one was a small man-made freshwater pond (site 16), and one was a small natural freshwater stream (site 19). On Curaçao, 3 sites were considered natural, 9 sites were adjusted by man (constructed dams, channels) and 5 were completely man-made. At three sites (4, 8 and 9), there was flowing water.

Sampling

Samples were collected during a three week survey in July 2006. Eleven days were spent on Curaçao, seven days on Bonaire and three on Aruba, where respectively 18, 16 and 10 locations were visited. In addition, three sites on Bonaire were sampled in January 2006.

Intensive sampling was done during three hours at each sampling site using triangular foldable dip nets for shallow water, and a 2 centimeter mesh multifilament beach seine for larger waters or lakes. The altitude of the location was recorded and the maximum basin size was estimated, as well as the actual water surface in square meters at the moment of sampling. For each locality the water body was characterized as either standing or flowing, and it was marked whether the water body was natural, semi-natural (altered by making concrete streambed floors or walled sides to a stream) or man-made. Water samples were taken to measure salinity (mS).

The fish samples were preserved in ethanol 96%, sorted and identified at the Zoological Museum Amsterdam. Specimens were counted and measured (body

length SL) for each location. Specimens collected are registered in the ZMA reference collection.

Analysis

A hierarchical cluster analysis based on Euclidian distances was conducted in SPSS for Windows to test whether sites on different islands were indeed distinctly differing in their species composition. The relationships between species composition and salinity, species composition and water basin type, and presence-absence of native and exotic species, were tested using non parametric tests (Mann-Whitney U, Spearman’s correlation, Chi-square and Fisher’s exact probability tests). Significance is accepted when P<0.05 in a two-tailed test.

Results

Intra- and inter-island species composition

A list of sites can be found in Table 1, with measurements of altitude, salinity, type of water body, type of basin, maximum size of basin and water surface size at the moment of sampling. A total of nine freshwater species is encountered in this study (Table 2). The most frequent species was the introduced tilapid *Oreochromis mossambicus* (Peters, 1852), followed by the endemic molly *Poecilia vandepolli* Van Lidth de Jeude, 1887 (it has been introduced to the island of St. Maarten, Poeser, 2003). Only two species occurred on all three islands: *O. mossambicus* and the guppy *Poecilia reticulata* Peters, 1859, which are both exotic species widely used for mosquito control (cf. Poeser et al., 2005). The ZMA holds additional specimens of the latter species from Bonaire (Poeser, 1992).

Table 2. Freshwater fishes documented at sampling sites 0.1-0.3 (January 2006) and 1-43 (July 2006). Key: +: specimen collected, o: observed, -: absent. Aruba: A, Bonaire: B, Curaçao: C.

Island code	B	B	B	C	C	C	C	C	C	C	C	C	C	C	C	C	C	B	B	B	B	A	A	A	A	A	A	A	A	A	A				
Site number	0.1	0.2	0.3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	34	35	36	37	38	39	40	41	42	43			
Fishes																																			
<i>Oreochromis mossambicus</i>	-	+	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	-	-	+	-	+	+		
<i>Poecilia vandepolli</i>	-	-	-	+	+	+	+	-	-	-	-	+	+	+	-	-	+	-	-	-	-	-	-	-	+	-	-	+	+	-	-	-	-		
<i>Poecilia reticulata</i>	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	0	+	-	-	-	-	-	-	+	+	-	-	-	-	-	-		
<i>Cyprinodon dearboni</i>	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-		
<i>Agonostomus monticola</i>	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-		
<i>Dormitator maculatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<i>Gobiomorus dormitor</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<i>Xiphophorus helleri</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	
<i>Awaous banana</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

On Aruba, four species were found, one of which - green swordtail *Xiphophorus helleri* Heckel, 1848 - as a new record for the island. This species was encountered only once with one single specimen. At all 10 sampling sites on Aruba fishes were caught.

Four species were reported for Bonaire, one of which, the mountain mullet *Agonostomus monticola* (Bancroft, 1834), was found only in brackish/marine waters. On this island, fishes were found at only 4 out of 18 sampling sites. The remaining sampling sites were either dried out (site 20 and 28) or did not provide any samples. Three additional sites on Bonaire sampled in January 2006, contained the broad killifish *Cyprinodon dearborni* Meek, 1909, *A. monticola*, and *O. mossambicus*; the latter was not encountered in July 2006.

On Curaçao, seven species were recorded, three of which were found only on this island: the eleotrid species *Dormitor maculatus* (Bloch, 1792), bigmouth sleeper *Gobiomorus dormitor* Lacepède, 1880, and the river goby *Awaous banana* (Valenciennes, 1837). The latter species was only observed at Hofi Pastor (site 15). On three other locations, sites 0.4, 0.5, and 0.6 (Table 1) no fishes were found after extensive sampling.

A hierarchical cluster analysis groups sites by species occurrence (Figure 2): three main clades are apparent. Clade 1 shows distinctly less Curaçao sites than those from Aruba and Bonaire, clade 3 includes mainly Curaçao sites, while clade 2 shows an equal mix of sites from all islands.

Salinity and occurrence of amphidromous species

Although the sites with the highest species-number were also the sites with low salinity, no significant relationship between species richness and salinity could be demonstrated (Spearman rank, $P = 0.34$). Likewise, although sites with amphidromous species present tended to have a higher salinity (median salinity = 8.31 milli Siemens per centimetre (mS/cm)) than sites where amphidromous species were absent (median salinity = 2.49 mS/cm) this difference was not statistically significant (Mann Whitney-U test, $n_1 = 8$, $n_2 = 21$, $P =$

0.067). Only non-amphidromous species were present on Aruba (10 sites). All sites on Curaçao with fishes also had non-amphidromous species. Bonaire’s ichthyofauna, in contrast, was dominated by amphidromous species (Table 3).

Effect of human-induced changes

We found no difference in the relative occurrence of exotic and indigenous between man-made and semi-natural, or natural sites (Fisher’s Exact Probability test, $P = 1.0$). Amphidromous species were not less common in altered sites than in natural ones (Fisher’s Exact Probability test, $P = 0.60$). Likewise species number was not affected by whether a site was in its natural state or was altered or man-made (Mann Whitney U test, $n_1 = 11$, $n_2 = 35$, $P = 0.078$). Relatively more exotic fish species were found on Aruba (3 exotic vs. 1 indigenous) than on Bonaire (1 vs 3) and Curaçao (2 vs 5) combined, however, this difference was not significant (Fisher’s Exact Probability test, $P = 0.26$)

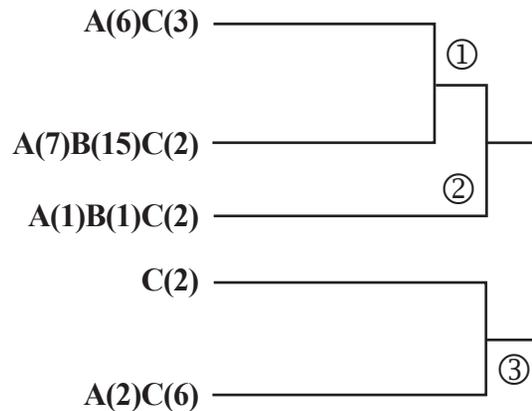


Figure 2. Dendrogram based on a hierarchical cluster analysis clustering sites by species occurrence. Key A: Aruba, B: Bonaire, C: Curaçao, with number of sites in parenthesis).

Table 3. Occurrence of amphidromous and non-amphidromous species in the Netherlands Antilles, during the dry season (July 2006).

	Sites with only amphidromous species	Sites with only non-amphidromous species	Sites with amphidromous + non amphidromous species	Sites without fish
Aruba	0	10	0	0
Bonaire	4	1	0	11
Curaçao	1	10	3	1

Discussion

Species composition and intra-island differences

During the survey in July 2006, eight of the total of thirteen reported freshwater fish species (Debrot 2003a) were recorded. Five species that were not found at the end of the dry season were the American eel *Anguilla rostrata* (Lesueur, 1817), the mangrove killifish *Kryptolebias marmoratus* (Huber, 2004), the emerald sleeper *Erotelis smaragdus* (Valenciennes, 1837), the small-scaled spinycheek sleeper *Eleotris perniger* (Cope, 1871), and the lyre goby *Evorthodus lyricus* (Girard, 1858). The highest number of species was found on Curaçao with seven species, while on both Aruba and Bonaire only four species were recorded. In the hierarchical cluster analysis (Figure 2) Curaçao stands out among the other two islands, and indeed differs in species composition. Aruban sites occur in 4/5 terminal branches, indicating that the Aruban ichthyofauna is a subset of Curaçao and Bonaire. Aruba and Bonaire are alike in terms of species richness, rather than species composition. Two of the four species occurring on both islands overlap, viz. *P. reticulata* and *O. mossambicus*, the two species widely used for mosquito control. The lack of further overlapping species between Aruba and Bonaire argues against the grouping of the two island locations in one clade, and supports the notion that at least during the dry season, species compositions of Aruba and Bonaire are very different.

Curaçao retains more freshwater in the dry season than the other two islands, and has mixed basin-types (3 natural sites, 6 adjusted sites and 6 completely man-made sites). Specifically, more continuously flowing ditches and channelised streams occurred on Curaçao than on the other islands, offering habitat for species associated with rivers or large streams like *Awaous banana*, *Gobiomorus dormitor* and *Dormitator maculatus*.

Human-induced changes

Surprisingly, we could not demonstrate an effect of human-induced changes on the presence or absence of fish species in the Netherlands Antilles. Salinity did not have a noticeable effect on species-richness (cf Arthington et al., 2005), and the presence of exotic species did not have a clear effect on the indigenous species, nor did human alteration of the habitats have an influence on the occurrence of fish species.

The introduction of fish species for mosquito control may affect aquatic communities (Innal and Erk'ahan,

2006). *Oreochromis mossambicus*, introduced to the Caribbean in the last century for fisheries and aquaculture (Chakalall, 1993), is a large, fast growing, highly fecund species, and tolerates a wide variety of water conditions. It competes for food and nest space with the indigenous ichthyofauna (Baird, 1976; Canonico et al., 2005; McCrary et al., 2007). *Oreochromis mossambicus* was not recorded from Bonaire during the dry season (July 2006), but was sampled in the wet season (January 2006), suggesting that this species declines severely in numbers under arid conditions, and therefore may not pose a grave threat to the indigenous species. In 8 / 11 sites where *O. mossambicus* was recorded on the other islands, no other fish species were seen. However, a mere 2 / 11 of these sites comprised natural water bodies. *Oreochromis mossambicus* is mainly used for mosquito control in new non-natural aquatic systems, and once introduced into a suitable habitat they generally establish themselves very quickly (Perez, 1999).

Xiphophorus helleri has expanded its area that was originally Mexico and Honduras to the Southern United States and has had viable populations in for instance Florida (Courtenay et al., 1974; Shafland, 1996). The specimen we caught on Aruba was a red female, obviously an aquarium variant, and it remains to be seen how well this species can establish itself permanently in ponds that have no raised salinity.

We demonstrated clear differences in the ichthyofauna of the three islands of the Netherlands Antilles during the dry season, with Curaçao being the most diverse, probably due to its having the most habitats and freshwaters present throughout the year. We could not demonstrate clear effects of human-induced disturbances, be it modifications of water bodies or the introduction of exotics, but we have to acknowledge that we lack information on any of the three islands' ichthyofauna in its pristine state. Other islands in the Southern Caribbean are equally disturbed, or are significantly different in size, hampering comparisons which could provide insight into the ichthyofauna of the region in its natural state. More detailed, and preferably longer, studies in the islands' last remnants of natural habitat are needed to obtain a more complete picture of the islands' indigenous ichthyofauna.

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