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Chapter 9

Fishes of Lely and Nassau Mountains, Suriname

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ABSTRACT

The fish fauna of Lely Mountains and Nassau Mountains was sampled at 4 and 3 sites, respectively, during a Rapid Assessment Program expedition in November 2005. A total of 36 species were identified. Of these, 26 were collected in a lowland stream in the foot hills of Nassau Mountains (altitude 106 m above mean sea level). The fish fauna of 4 high-altitude (plateau) streams in Lely Mountains had 8 species. In high-altitude reaches of one stream in Nassau Mountains (Paramaka Creek) we collected 6 fish species, including the endemic catfish *Harttiella crassicauda*. A second survey of plateau streams in Nassau Mountains in March/April 2006 increased the number of species to 41; 11 species, including 6 species that are potentially new species to science, were collected from high-altitude streams. The low number of fish species in the high-altitude streams of Lely and Nassau Mountains was expected, but the high number of potentially new (and endemic?) species in Nassau Mountains was exceptional. A diet consisting of filamentous (red) algae, diatoms and fine detritus, low fecundity (3-7 large, mature eggs per female), and sedentary habits make *Harttiella crassicauda* of Nassau Mountains highly vulnerable to human impact on its habitat (e.g. mining-related siltation and sedimentation, and habitat loss). The steep slopes bordering the Nassau Plateau apparently act as biogeographic barriers that prevent the dispersal of fishes from one high-altitude stream to the other streams on the plateau. For example, *Harttiella crassicauda* from the central branch of Paramaka Creek (IJskreek) differed morphologically from *H. crassicauda* collected in a northern branch of Paramaka Creek (the two tributaries joining each other in the foot hills of Nassau Mountains). A new loricariid species (nicknamed 'big mouth') from the northern branch of Paramaka Creek was not collected in the central branch (IJskreek), notwithstanding extensive collection efforts at the latter site. Paramaka Creek with its large catchment on the plateau had most of the unique fish species of Nassau Mountains and should be carefully protected. However, other high-altitude streams of Nassau Mountains were sampled only once (or not at all) and they should be inventoried more thoroughly in the future. The genus *Lithoxus* of high-altitude streams of Nassau Mountains should be studied in detail including analysis of its DNA. Both Nassau and Lely Mountains are concessions of bauxite mining companies. In the foot hills, small- and large-scale gold mining, forestry and shifting cultivation threaten the pristine wilderness character of the forest and streams. Because of its geographical location close to the densely populated coastal plain and its accessibility by road, these threats have a more immediate character in Nassau Mountains as compared to Lely Mountains. The Surinamese government should collaborate with local and international organizations and the concession holder in a comprehensive effort to protect Nassau Mountains and preserve its unique flora and fauna for future generations.

INTRODUCTION

The Neotropics has more species of freshwater fishes than any place else in the world. Most Neotropical freshwater fish species live in lowland streams, and effort to collect fishes of high-altitude mountain streams has been relatively small compared to collection effort in lowland streams. The Guayana Shield in northern South America has many isolated sandstone table mountains (tepuis) and other mountains with low level of ichthyological understanding. During the 2002 Guayana Shield Priority-Setting workshop, the fish-specialist group identified the Nassau-Lely Mountains as a priority area with high need for biological surveys (Lasso et al. in Huber and Foster 2003), an assessment based mainly on the occurrence of the endemic catfish *Harttiella crassicauda* (Boeseman 1953) in Nassau Mountains and ecological/evolutionary phenomena related to the occurrence of this unique species in Nassau Mountains.

Nassau (~20x20 km^2), Lely (~30x30 km^2), and Brownsberg Mountains are flat-topped, bauxite- or laterite-capped mountains (so-called denudation surfaces; King et al. 1964) in eastern Suriname which escaped erosion during the Tertiary Period because of their protective duricrust (Noordam 1993). In the 2002 Guayana Shield Priority-Setting workshop these mountains were grouped in the Maroni Area (20,600 km^2), an area of the highest biological importance and with great scenic beauty and potential for ecotourism (Huber and Foster 2003). Preliminary results of surveys of plant diversity of the three mountains indicated high diversity of mountain forests compared to lowland forests and suggest that the three mountains may constitute a unique ecosystem in Suriname (Bánki et al. 2003, ter Steege et al. 2004, 2005). Although the foot hills of the mountains and the lowlands separating the mountains are heavily impacted by small (gold) and large (gold, bauxite) mining operations, logging, hunting, fishing and damming (Brokopondo Reservoir), the forests on the mountain plateaus are still largely untouched. Here we present the results of an inventory of the fish fauna of Lely and Nassau Mountains in the period 25 October – 7 November (i.e. dry season; Amatali 1993). Because access to high-altitude streams of Nassau Mountains Plateau was rather limited during the RAP survey, we include results of a second survey of Nassau streams (29 March – 4 April 2006; short rainy season) in the present report. We close with some remarks on potential environmental impacts on the fishes of these mountain streams.

Biogeography

Suriname, up to 1975 known as Dutch Guiana, is a small country (163,820 km^2; population 480,000) in northwestern South America between 2-6°N and 54-56°W. To the east is French Guiana, to the west is Guyana, to the south is Brazil, and to the north is the Atlantic Ocean. Suriname covers about 10% of the 2.5 million km^2 Precambrian Guayana Shield, a thinly inhabited area (0.6-0.8 humans/ km^2) in northern South America covered with pristine rain forests, savannas and palm marshes. A characteristic feature of the Guayana Shield are the tepuis or sandstone table-mountains (e.g., Tafelberg Mountain in the upper Coppename basin).

Three major geographical zones can be distinguished in Suriname: the Coastal Plain, the Savanna Belt, and the Interior. Bordering the Atlantic Ocean is the Coastal Plain with Andean/Amazon-derived clays deposited in the Quaternary Period by the Guiana Current (Noordam 1993). Habitats in the Coastal Plain zone include mangrove forests, brackish-water lagoons and river estuaries, fresh- and brackish-water swamps, agriculture lands (rice fields), and marsh forests. This zone is the most accessible, densely populated and disturbed area of Suriname. The fish fauna of the Coastal Plain has many brackish-water species and juveniles of marine species and a small number of freshwater-swamp fishes.

To the south of the Coastal Plain is the Savannah Belt with Pliocene sandy sediments deposited along the northern edge of the Guayana Shield by braided rivers from the Interior. It is characterized by savannas and savanna forests drained by black-water streams (e.g., Cola Creek, Blaka-Watra Creek). The black-water streams have many small fish species that are common aquarium species (e.g., pencil fishes and tetras).

The great majority of Surinamese freshwater fishes live in seven river systems draining the *terra firme* rainforest of the Interior, from west to east: Corantijn River (with tributaries Nanni, Kaboeri, Kabalebo, Lucie, Zuid, Coeroeni, Sipaliwini, and Oronoque), Nickerie River (with tributary Maratakka), Coppename River (with tributaries Coesewijne, Tibiti, Wayombo, Adampada, Rechter Coppename, Midden Coppename, and Linker Coppename), Saramacca River (with tributaries Mindrineti, and Kleine Saramacca), Suriname River (with tributaries Para, Sara, Gran Rio and Pikien Rio, and the hydroelectric reservoir Lake Brokopondo (Lake Van Blommestein; dam completed in 1964)), Commewijne River (with tributaries Cottica, and Mapane), and Marowijne River (with tributaries Lawa, Tapanahoni, Paloemeu, Gonini, Oelemari, and Litani). The border rivers, Corantijn in the west and Marowijne in the east, together drain nearly half of the Surinamese land surface (Amatali 1993). The Interior is hilly with Precambrian Shield rocks (80% of Suriname's land surface), but predominantly low-lying with only few mountains rising above the 250 meter contour. The water of streams in the Interior that drain the old, weathered Precambrian Guayana Shield is mostly clear (Secchi transparency up to 3 m) and poor in sediment (0.001-0.1 g/l) and nutrients. Streams in Nassau (564 m above mean sea level) and Lely (694 m.amsl) Mountains drain to Marowijne River.

History of fish collecting in Nassau and Lely Mountains

A history of freshwater fish collectors in Suriname is given in Mol et al. (2006). Fishes of Nassau Mountains were collected in 1949 by D.C. Geijskens and P.H. Creutzberg (Boeseman 1953; Appendix 10). To our best knowledge, fishes have not been collected in Lely Mountains prior to the present RAP survey of November 2005.

Geijskens and Creutzberg collected 19 fish species in the Nassau mountains (Appendix 10), including 15 specimens of *Harttiella crassicauda*. Boeseman (1953) does not provide altitude of the collection localities of Geijskens and Creutzberg, but from collection dates and known habitat preference of fish species like *Serrasalmus rhombeus*, *Pimelo-*

dus ornatus, *Platydoras costatus*, *Megalechis thoracata*, *Helogenes marmoratus*, *Rhamdia quelen*, and *Astyanax bimaculatus* (all lowland species) we can infer that all but two species (*Harttiella crassicauda* and 6 specimens of *Trichomycterus guianensis*) were collected in lowland streams in the foot hills of Nassau Mountains. Three new fish species (*H. crassicauda*, *Heptapterus bleekeri* and *Hemibrycon surinamensis*) have been described from the 176 specimens collected in Nassau Mountains by Geijskens and Creutzberg and the small collection also yielded one new record for Suriname (*Chasmocranus brevior*). However, the collection of Geijskens and Creutzberg was not representative for the fish fauna of high-altitude streams of the Nassau Plateau.

METHODS

At seven collection sites in mountain streams in Lely (L1-L4; 25-31 October, 2005) and Nassau (N1-N3; 1-7 November, 2005) Mountains (Figure 9.1, Table 9.1), we measured pH with pH-paper, conductivity and temperature with an YSI-30 meter and transparency with a Secchi disc. Water samples with 2% vol. vol. H_2SO_4 added were analyzed for N, P and C nutrients in FIU-Southeast Environmental Research Center Water Quality laboratory (http://serc.fiu.edu/sercindex/index.htm) following standard Environmental Protection Agency (EPA) methods and American Standard Methods (ASTM). In IJskreek (Nassau Mountains, N1) we also sampled tufts of filamentous algae from boulders and, during a second survey (29 March – 4 April 2006; see Discussion), phytoplankton in 1-liter bottles (5 ml of 4% formalin added); periphyton and phytoplankton samples were analyzed by A. Haripersad-Makhanlal of Hydraulic Research Division (Waterloopkundige Afdeling WLA), Ministry of Public Works, Paramaribo.

During the March/April 2006 survey of Nassau Mountains we measured instream fish habitat of *Harttiella crassicauda* in the headwaters of Paramaka Creek (IJskreek tributary; N1) on the basis of depth, current velocity and substrate type following Gorman and Karr (1978). Point samples of depth, substrate, and current velocity were taken along transects perpendicular to the stream, beginning 10-20 cm from the left bank and then at 1-m intervals across the stream. Repeated sets of measurements were taken across the stream at 5-m intervals moving upstream. At each measurement point, depth was measured with a meter stick, current velocity was measured by recording the time required for a floating object to travel 1 m downstream. Substrate type was classified into one of ten categories (Appendix 14). Depth and current measurements were divided into four and six categories, respectively (Appendix 14), to facilitate computation of a habitat diversity index. Categories were chosen as representative of the habitats in the small mountain streams (e.g., shallow edges, 0-10 cm; riffles11-20 cm; pools, 20-30 cm and deep pools >30 cm). Frequencies of occurrence (p_i) of each habitat category or combination of depth, current, and substrate were used to calculate a Shannon-Wiener index of habitat diversity, $H = -\Sigma\ (p_i)^*(\ln p_i)$ (Krebs 1989).

We used 3-m seine (specifications, length = 3 m, height = 2 m, mesh size = 0.5 cm), a 30-m gill net (mesh-size 3 cm), and rotenone to investigate fish communities. During the March/April survey at Nassau Mountains we also used a Smith-Root Model 12B electrofisher (DC output up to 1,100 V) in combination with a seine net set in the current. In shallow mountain streams with weak or moderate

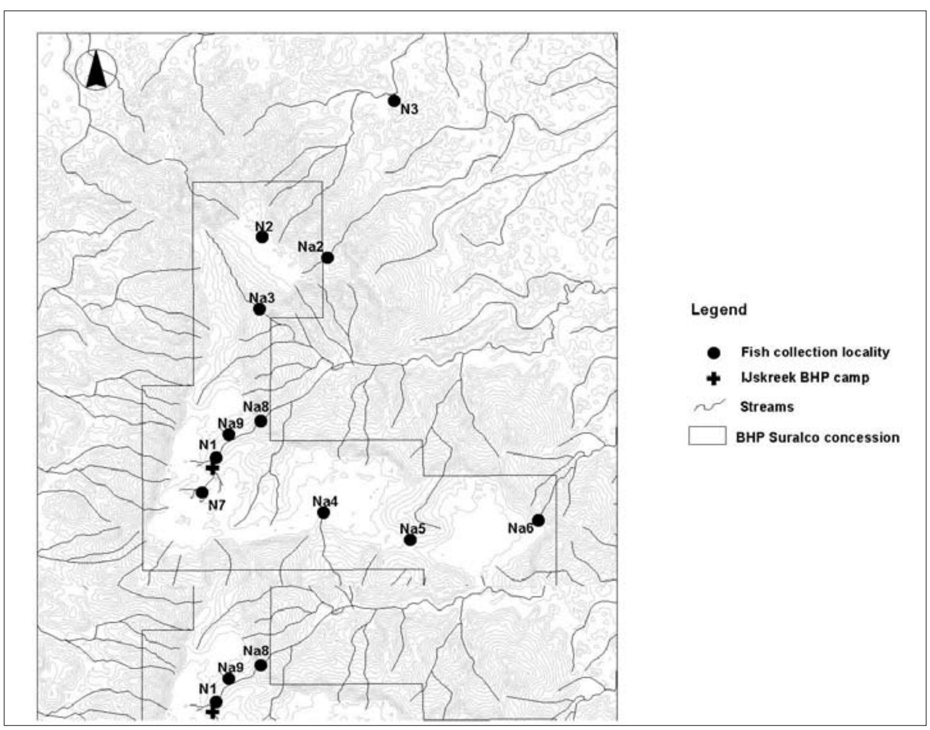

Figure 9.1. Map of Nassau with sampling locations.

current the seine was pulled; in riffles with strong current the seine was set and held in place and upstream rocks were kicked out or fishes were chased from their hiding places with the electrofisher. The gill net was used on one occasion in a medium-sized stream in the foot hills of Nassau (N3). Rotenone was used in four streams with weak current (L2, L3, N1 and N3) to check the completeness of seine samples. When a particular area was chosen we sampled all available habitat types observed, e.g. pools, riffles, root masses, leaf litter, and woody debris.

We sampled in daylight only, although on one occasion we collected the nocturnally-active fishes swamp eel *Synbranchus marmoratus* and armored catfish *Callichthys callichthys* at night. One collection took one to four hours. In total we made 7 collections, 4 in Lely Mountains and 3 in Nassau Mountains. During the March/April 2006 survey of high-altitude streams in Nassau Mountains we made 7 collections in four different streams. Fishes were preserved in 4% formalin and later transferred to 70% ethanol for long term storage at National Zoological Collection of Suriname

Table 9.1. GPS-coordinates of collection sites and water quality of streams in Lely (L1-L4) and Nassau (N1-N3) Mountains, Suriname, 25 October – 7 November 2005. Collection site N2 is a shallow depression (swamp) with standing water. Nutrient concentrations are based on the atomic weight of primary nutrient species (ppm-N, ppm-P, ppm-C), not the molecular weight.

	Lely Mountains				Nassau Mountains		
	L1	L2	L3	L4	N1	N2	**N3**
GPS-coordinates (Deg/Min/Sec)	N04/16/13.5, W54/44/17.2	N04/15/8.9, W54/43/54.8	N04/15/52.7, W54/43/47.2	N04/15/24.1, W54/44/40.9	N04/49/13.7, W54/36/20.6	N04/52/55.8, W54/35/33.5	N04/55/12.5, W54/33/20.6
Altitude (m.amsl)	650	400	?500	550	467	514	106
Date	26 Oct 2005	27 Oct 2005	28 Oct 2005	29 Oct 2005	2 Nov 2005	3 Nov 2005	4 Nov 2005
Time	08.30 AM	10.00 AM	09.00 AM	09.00 AM	07.50 AM	09.45 AM	09.30 AM
Stream width (m)	1	3	2	2	1.5-3	-	4
Water depth (cm)	40	150	50	50	40	20	190
Conductivity (µS/cm)	25.2	23.5	22.6	26.3	27.9	43.6	22.8
Water temperature (ºC)	22.2	23.3	22.6	22.5	22.6	23.4	24.8
pH	6.5	7.5	7	7	7	7	7
Secchi transparency (cm)	>40	>150	>50	>50	>40	>20	>100
Color	transparent	transparent	transparent	transparent	Transparent	light brown	transparent
NO_3–N (ppm)	0.030	0.087	0.060	0.074	0.023-0.099	0.017	0.105
NO_2–N (ppm)	0.002	0.002	0.002	0.002	0.002-0.002	0.003	0.002
NH_4-N(ppm)	0.030	0.017	0.029	0.044	0.018-0.042	1.447	0.071
Total inorganic N (ppm)	0.062	0.106	0.091	0.120	0.067-0.120	1.466	0.178
Total organic N (ppm)	0.627	0.479	0.405	0.337	0.307-0.592	0.812	0.993
Total-N (ppm)	0.689	0.585	0.496	0.457	0.393-0.708	2.279	1.170
Dissolved-P (ppm)	0.004	0.002	0.002	0.004	0.001-0.006	0.053	0.002
Total-P (ppm)	0.008	0.170	0.005	0.003	0.002-0.010	?	0.006
Total organic C (ppm)	5.691	4.475	5.386	4.488	2.916-4.972	35.740	4.472
Remarks	weak current	moderate to strong current	weak current	weak current	*Harttiella crassicauda* present	Swamp with standing water	disturbed by gold miners

(NZCS) in Anton de Kom University of Suriname, Paramaribo, Suriname, Field Museum (FMNH), Chicago, and Smithsonian Institution, Washington D.C.

Identifications were made to the lowest taxonomic level possible. Usually this meant to species, but one juvenile specimen could only be identified to genus. Publications used to identify the fishes included regional contributions like 'The Freshwater Fishes of British Guiana' (Eigenmann 1912) and 'Atlas des Poissons d'Eau Douce de Guyane' (Planquette et al. 1996, Keith et al. 2000, Le Bail et al. 2000), general taxonomic treatises like 'Characoids of the World' (Géry 1977), and taxonomic surveys specific to Suriname like 'The Cichlids of Surinam' (Kullander and Nijssen 1989), 'The 'comb-toothed' Loricariinae of Surinam' (Boeseman 1971), and many others.

Identification of *H. crassicauda* was confirmed by Raphael Covain, Museum d'Histoire Naturelle, Geneva, Switzerland, specialist in the subfamily Loricariinae (e.g. Covain et al. 2006). Approximately 50 specimens of *Harttiella crassicauda* were collected in IJskreek (site N1) during the RAP survey in November 2005; 25 specimens were preserved in 4% formalin (and later transferred to 70% ethanol for long-term storage in museums in Suriname, Switzerland and USA), 10 specimens were preserved in 95% ethanol and send to Raphael Covain for analysis of mtDNA, 5 specimens were used for analysis of stomach (intestines) contents, and 10 specimens were kept alive for observation of their behavior in aquarium. We obtained the first photographs of live *H. crassicauda* in its natural habitat (see photo pages). During the second survey in Nassau Mountains (March/April 2006) we collected 40 specimens of *H. crassicauda* and an additional 40 specimens of a second *Harttiella* population in a northern tributary of Paramaka Creek; these specimens were send to the museum of the Universidade de Sao Paulo (MZUSP) and Geneva Museum, or used in (1) stomach (intestines) contents, (2) fecundity analysis, (3) tissue analysis for metals and stable carbon isotopes, and (4) DNA analysis.

RESULTS

We collected 787 specimens in 36 species in 6 streams and 1 palm swamp in Lely and Nassau Mountains (Appendix 11). These 36 species can be divided into 6 orders and 15 families. The largest order is Characiformes (14 species, 39% of the total), followed by Siluriformes (11 species, 31%), Perciformes (5 species, (14%), Gymnotiformes (4 species, 11%), Cyprinodontiformes (2 species, 6%), and finally Synbranchiformes (1 species, 3%). The largest families are Characidae and Loricariidae (each 6 species, 17%), followed by Cichlidae (4 species, 11%), and Erythrinidae, Lebiasinidae (each 3 species, 8%) with other species comprising 39%. Of the 36 species, two (6%) are new to science: *Lithoxus* sp.1 and *Trichomycterus* aff *conradi*. The endemic catfish *Harttiella crassicauda* (Boeseman, 1953) was collected for the first time since its original discovery by Geijskens and Creutzberg in 1949. During the second survey of high-altitude streams in Nassau mountains we collected an additional four species that may prove new to science.

In Lely Mountains we collected 260 specimens in 8 species from 4 high-elevation streams (Table 9.2). In Nassau Mountains we collected 338 specimens in 6 species in one high-elevation stream (N1, IJskreek) and one swampy depression (N2, one species only: *Rivulus* cf. *igneus*), and 189 specimens in 26 species from a lowland stream in the foot hills at altitude 106 m.amsl (N3). The lowland stream had higher species richness than the mountain streams in Lely and Nassau Mountains, but loricariid and trichomycterid catfishes (eight species in total) were collected only in high-altitude streams on the plateau. In Nassau Mountains, only two species (swamp eel *Synbranchus marmoratus* and *Rivulus* cf. *igneus*) were collected in both high-altitude stream and lowland stream in the foot hills.

Shallow headwater streams in Lely (L1, L3 and L4) and Nassau (N1, upstream of temporary BHP-Billiton exploration camp) Mountains had only two or three fish species, i.e. *Rivulus* cf. *igneus*, *R.* cf. *lungi*, swamp eel *S. marmoratus* and armored catfish *C. callichthys*. All these species are capable of moving some distance over land (Ouboter and Mol 1993) and they are also able to use oxygen from the air for breathing (Graham 1997). In addition, *Rivulus* is able to climb vertical rocks in water falls (Eigenmann 1912). These species are thus able to re-colonize ephemeral headwater streams from downstream pools once the headwater streams receive water in the rainy season. More downstream (but still on the plateau), streams of Lely and Nassau Mountains had about 6-8 fish species (L2, N1 downstream of BHP-camp), including the endemic species from Nassau Mountains (see below). The large stream in the foot hills of Nassau Mountains (N3) had most species (26). Abundances of individuals of most species were high. The only species that was collected in low numbers was the predatory swamp eel *S. marmoratus*

Table 9.2. Fishes collected in high-altitude (plateau) streams and one lowland stream (foot hills) of Lely and Nassau Mountains (in number species and number of specimens), 25 October – 7 November 2005.

	Number of species				Number of specimens			
	Lely		Nassau		Lely		Nassau	
	N	%	N	%	N	%	n	%
Plateau	8	100	6	19	260	100	338	64
Foot hills	-		26	81	-		189	36
Total	**8**	**100**	**32**	**100**	**260**	**100**	**527**	**100**

(although this species was present at most collection sites; Appendix 11).

Lely Mountains

Lely Mountains (altitude up to 694 m.amsl) is a very pristine area in the Marowijne River Basin. Access to the plateau is difficult and mostly restricted to small airplanes. At present the only human activities in Lely Mountains are related to three personnel of the Aviation Service (Sur. Luchtvaartdienst) at the airstrip on the plateau and one camp of small-scale gold miners in the western foot hills. We surveyed four high-altitude (i.e. >400 m.amsl) streams that were undisturbed other than by natural processes. The streams had clear water (Secchi transparency >150 cm at L2), with low conductivity (22.6-26.3 µS/cm), relatively low water temperature (22.2- 23.3 °C), pH 6.5-7.5, low inorganic N nutrients (0.062-0.120 ppm), 0.337-0.627 ppm organic N, 0.002-0.004 ppm dissolved P (0.003-0.170 ppm total P), and 4.475-5.691 ppm organic C (Table 9.1).

We made four collections in Lely Mountains: three collections in shallow, low-gradient streams at high altitude (>500 m. amsl) and one collection in a slightly larger stream with higher gradient at altitude 400 m.amsl (L2). In the three high-altitude streams we collected/observed only three fish species: swamp eel *Synbranchus marmoratus* and two *Rivulus* species (killifishes), *Rivulus* cf. *igneus* and *R.* cf. *lungi* (Appendix 11). *Rivulus* were abundant and in good condition, e.g. bright colors, no fish parasites, many large-sized specimens. In the stream at 400 m altitude we collected six fish species: two *Rivulus* species (*R.* cf. *igneus* and *R.* cf. *lungi*) and three loricariid catfishes (*Ancistrus temminckii*, *Guyanancistrus brevispinnis*, and *Lithoxus surinamensis*) and the trichomycterid catfish *Ituglanis* cf *amazonicus* (Appendix 11).

Nassau Mountains

Nassau Mountains has a slightly lower altitude (564 m.amsl) than Lely Mountains. At the high-altitude plateau (> 400 m.amsl), the forest and streams of the Nassau Mountains were mainly intact (e.g. we observed large-sized trees and clear water in IJskreek at 460-535 m.amsl). However, we observed many human activities in the foot hills of Nassau Mountains, e.g. shifting cultivation plots, logging, small-scale gold mining, and exploration for construction of a large goldmine (Newmont). We collected fishes in one high-altitude stream (N1, IJskreek, 460-535 m.amsl; Figure 9.1) and a palm swamp (N2, 560 m.amsl; Figure 9.1) on top of the plateau, and in one low-altitude stream (N3, 106 m.amsl) in the foot hills of the northwestern slope. *Harttiella crassicauda* was collected only in Paramaka Creek (IJskreek tributary, N1). The headwaters of IJskreek had clear water (Secchi transparency> 50 cm) with low conductivity (25.9-31.8 µS/cm), pH 7, low water temperature 22.6 °C, low inorganic N (0.067-0.120 ppm), 0.307-0.592 ppm organic N, 0.03-0.010 ppm total P, and 2.916-4.972 ppm organic C (Table 9.1). At sites where gaps in the closed canopy allowed sunlight to reach the water surface we observed tufts of filamentous red (*Batrachospermum* spp dominant) and green (*Spirogyra* sp) algae attached to boulders; these filamentous algae had large populations of epiphytic diatoms (*Eunotia* spp) attached to their branches (Appendix 12). We observed only one aquatic macrophyte (*Thurnia sphaerocephala*) in a 100-m reach of IJskreek downstream N1 (about 200 m upstream of site Na8; Figure 9.1). Phytoplankton concentrations of IJskreek were low during the March/April 2006 survey (0-5 individuals per liter; Appendix 12). The palm swamp had higher conductivity 43.6 µS/cm, pH of 7, clear-brownish water with temperature of 23.4 °C, high inorganic N nutrients (1.466 ppm, including 1.447 ppm NH_4), 0.053 ppm dissolved P, and high organic C (35.740 ppm) (Table 9.1). Anjumarakreek at 106 m.amsl had conductivity of 22.8 µS/cm, pH 7, high Secchi transparency >100 cm, water temperature of 24.8 °C, 0.178 ppm inorganic N, 0.993 ppm organic N, 0.006 total P, and 4.472 ppm total organic C (Table 9.1).

On the plateau IJskreek (460-535 m.amsl) showed characteristics of a stepped system rather than a continuous gradient. During the November survey (dry season) the headwaters of the stream, a 200-m long, low-gradient reach on top of the plateau (altitude 528-535 m.amsl; N7 in Figure 9.1), were completely dry. At the BHP Billiton exploration camp (528 m.amsl; Figure 9.1), the stream consisted of a 300-m reach of unconnected, shallow pools with standing water, also with low gradient. During the March/April 2006 survey, IJskreek had running water all the way up to its sources 200 m upstream of BHP-Billiton exploration camp (the same March/April situation with flowing water was also observed on 22 July (long rainy season)). Finally, we surveyed a 2500-m-long reach with running water to the edge of the plateau (2.7 km downstream of BHP camp); this reach (N1-Na8 in Figure 9.1) showed alternating high-gradient small falls and low-gradient reaches with riffles-and-pools habitat. In the pools with standing water near BHP camp we collected three fish species: armored catfish *C. callichthys* (Sur. platkop kwikwi), swamp eel *S. marmoratus* and *Rivulus* cf. *igneus*. About 400 m downstream of BHP exploration camp, in running water, we caught the endemic loricariid catfish *Harttiella crassicauda* (see below), together

Table 9.3. Lists of species of high-altitude streams of Nassau Mountains Plateau that are potentially new species to science.

Potentially New Species from Nassau Mountains
Guyanancistrus sp. 'big mouth'
Harttiella cf. *crassicauda (*slender *Harttiella* from northern tributary of IJskreek)
Lithoxus sp. 1
Lithoxus sp. 2 (forked caudal fin)
Lithoxus sp. 3 (with yellow spots on its head)
Trichomycterus aff *conradi*

with swamp eel *S. marmoratus*, *R.* cf. *igneus*, and the catfishes *C. callichthys*, *Lithoxus* sp.1 and *Trichomycterus* aff *conradi*. During the March/April survey and on 22 July 2006 we collected only *C. callichthys* and *Rivulus* cf. *igneus* in IJskreek upstream of BHP camp (i.e. in the 200-m reach N7 that was completely dry in November 2005).

In the high-altitude palm swamp we caught only one fish species (*Rivulus* cf. *igneus*; Appendix 11). In the lowland stream in the foot hills of Nassau Mountains we collected 26 fish species (Appendix 11), but *Harttiella crassicauda* was conspicuously missing in the catch from this lowland site.

During the RAP expedition in November 2005 we had access to only one high-altitude stream on Nassau Plateau (IJskreek, N1). Although we collected only 6 fish species in IJskreek, we were not able to identify two of these species (*Lithoxus* sp. 1 and *Trichomycterus* aff *conradi*; both species are probably new to science), while a third species (*Harttiella crassicauda*) is known to be endemic for Nassau Mountains (e.g. Le Bail et al. 2000). During a second survey of streams draining Nassau Plateau (29 March – 4 April 2006) we had the opportunity to collect fishes in three additional high-altitude streams in Nassau Mountains and two additional tributaries of Paramaka Creek (a northern and a southern tributary) (Figure 9.1; Appendix 13). In a northern tributary of Paramaka Creek we collected a new *Guyanancistrus*-like dwarf catfish (nicknamed 'big mouth') and a slender *Harttiella* (sub)species. We also collected two additional *Lithoxus* species (one species with a forked caudal fin and one species with small, yellow spots on its head) that may prove new to science. Taking into account the results of the second Nassau survey, we have collected 11 fish species from high-altitude (plateau) streams in Nassau Mountains: 3 ubiquitous species with adaptations to colonize high-altitude streams (*S. marmoratus*, *C. callichthys* and *Rivulus* cf. *igneus*), 1 *Ancistrus* species, the endemic catfish (*Harttiella crassicauda*), and 6 (54%) species that are potentially new species to science (Table 9.3).

Interesting species: *Harttiella crassicauda* (Boeseman, 1953)

The loricariid (suckermouth) catfish *Harttiella crassicauda* was collected only once (1949) prior to the present RAP expedition of November 2005. In 1949, D.C. Geijskes collected 15 specimens of *H. crassicauda* in a 'creek in Nassau Mountains' (Boeseman 1953); these 15 specimens were deposited in Naturalis Museum (formerly Rijksmuseum van Natuurlijke Historie - RMNH), Leiden, the Netherlands. In 1953, the new species from Nassau Mountains was described by M. Boeseman as *Harttia crassicauda*. In 1971, Boeseman created a new genus *Harttiella* to accommodate this unique species. At present, *H. crassicauda* is still the only species in the genus *Harttiella* (Ferraris 2003). We took the first photograph of a live specimen of *Harttiella crassicauda* in its natural habitat, IJskreek, Nassau Mountains (see photo pages).

Harttiella crassicauda is the smallest species (maximum length 5 cm SL) of the large subfamily Loricariinae (31 genera, 209 species; Ferraris 2003). The tribe Harttiini (Isbrücker and Nijssen 1978) or 'comb-toothed' Loricariinae, including *H. crassicauda*, is diagnosed as having the dorsal fin approximately opposite the ventral fins, the caudal fin with 12 branched rays, numerous bilobed teeth that form a comb, and usually a strongly depressed body. *Harttiella crassicauda* looks like a dwarf *Harttia* species, but with a body that is only moderately depressed (especially its caudal peduncle), a broad, rounded snout, rounded and indistinct carinae, and a naked belly. In systematic studies, the Harttiini are usually positioned at the base of the Loricariinae tree (e.g. Montoya-Burgos et al. 2003). Isaäc Isbrücker (1980) hypothesized that *H. crassicauda* is ancestral to all species of the subfamily Loricariinae, making it a key species/genus to understanding of the systematics of the family Loricariidae. Preliminary results of analysis of mtDNA of *H. crassicauda* and other Loricariinae (Covain and Mol, unpublished results) confirm the ancestral position of Harttiini at the base of the Loricariinae tree, but show *H. crassicauda* derived from a *Harttia* species (either *H. guianensis* or *H. surinamensis*).

Harttiella crassicauda is probably restricted in its geographical distribution to the Nassau Mountains, where it was collected in a 2500-m reach (IJskreek, altitude 370-530 m; N1-Na8, Figure 9.1, see also photo pages) of a single stream (Paramaka Creek) on the plateau (a second *Harttiella* population with a more slender body was discovered during a survey in March/April 2006 in a northern tributary of Paramaka Creek; Appendix 13). In these high-altitude reaches of Paramaka Creek, *H. crassicauda* was apparently not rare: on four occasions 10-12 specimens were collected in a single seine haul. They were collected both in 'deep' (up to 50 cm) pools on bedrock and boulders and in shallow riffles among gravel substrate (Appendix 14). However, *H. crassicauda* was not collected in Lely Mountains to the south of Nassau Mountains (Appendix 11), in Brownsberg Mountains (J.H. Mol & P.E. Ouboter, pers. observations) and Bakhuis Mountains (Hydrobiology 2006) to the west of Nassau, in lowland streams of the Suriname River Basin (Mol et al. in prep), and in three other high-altitude streams of the Nassau Plateau (Appendix 13). *Harttiella crassicauda* was also not collected to the east of Nassau in French Guiana (Le Bail et al. 2000) and it seems unlikely that it occurs in lowland streams to the north of Nassau (e.g. it was not collected in Anjumarakreek in the northwestern foot hills of Nassau Mountains, at altitude 106 m.amsl; site N3). Thus, to our best knowledge, the geographical distribution of *H. crassicauda* is restricted to one stream in Nassau Mountains (an area of about 20x20 km^2), a distribution unlike that of any other fish species in Suriname (or French Guiana; Planquette et al. 1996, Keith et al. 2000, Le Bail et al. 2000).

Because nothing is known about the biology and ecology of *H. crassicauda* and survival of this species in the near future is threatened by human activities in Nassau Mountains, it seems appropriate to present here some preliminary observations on behavior (aquarium), diet and fecundity of *H. crassicauda* that may help protecting this unique species. *Harttiella crassicauda* is a benthocryptic (see photo pages), dwarf suckermouth catfish that is mainly active at night (aquarium observations; Appendix 15), although some diurnal activity was also observed both in the aquarium and in its natural habitat (i.e. it was observed grazing on rocks in a deep pool at Na8). In April and July 2006, we did not collect *H. crassicauda* from the headwaters of IJskreek upstream of BHP-Billiton exploration camp (these headwaters were completely dry in November 2005) although the species was collected 400 m downstream of BHP camp both in November 2005 and March/April 2006; these observations indicate that *H. crassicauda* is rather sedentary and does not migrate even short distances in IJskreek. We examined 74 adult specimens and 27 juveniles from high-altitude reaches of Paramaka Creek; the largest specimen measured 49.3 mm TL (41.3 mm SL) and weighed 0.986 g. *H. crassicauda* has the long (4.3-4.6 times SL), coiled intestines and suction-cuplike ventral mouth with comblike rows of teeth of an aufwuchs (periphyton) feeder. Analysis of intestines contents (N=25; 5 adult specimens from November 2005, 20 adult specimens from March/April 2006) showed that in its natural habitat *H. crassicauda* fed mainly on fine detritus, filamentous red algae (*Batrachospermum* spp, *Ballia prieurii*, *Goniotrichum* sp) and epiphytic diatoms (mainly *Eunotia* spp). In the aquarium, *H. crassicauda* did not accept artificial feeds, but only fed on periphyton algae. Among the 5 specimens from November 2005 (dry season), one female (42.4 mm TL, 34.3 mm SL, 0.5800 g) had ripe ovaries, i.e. one ripe ovary with 19 eggs, 7 large, yolky eggs (0.8-2.0 mm diameter) and 12 small-sized developing eggs. In March/April 2006, *Harttiella* were reproducing in Paramaka Creek and we collected 27 juveniles (15.2-26.2 mm TL, 11.9-21.5 mm SL, 0.0187-0.1135 g wet mass) and 17 females with ripe ovaries (in all specimens we found only one ripe ovary per female). Female *Harttiella* had only 3-7 large, yellow, yolk-loaden (1.0-2.5 mm diameter) eggs. Most Loricariidae have spawns consisting of relatively few, large eggs and practice some type of brood care such as cleaning and defense of the spawn (and in virtually all species known to care, it is the male who does so), but the low number of 3-7 mature eggs per female in *H. crassicauda* is extreme even in the family Loricariidae.

A diet based on algae, a low fecundity, sedentary habits and restricted distribution all make *H. crassicauda* very vulnerable to increasing human activities in Nassau Mountains (mining, logging, shifting cultivation). *H. crassicauda* has to be considered an endangered species and it should be included in the IUCN red list of endangered species. Although most catfishes of the subfamily Loricariinae are of little economic interest (e.g. as food fishes) some species are popular with aquarium hobbyists (Evers and Seidel 2005). *Harttiella* is a sensitive species that is easily stressed (and easily dies) both during transportation and in the aquarium when disturbed by tank mates or deprived of shelter (Appendix 15); clearly *Harttiella* can not be recommended for beginner aquarium hobbyists, but even in the case of specialist breeders (e.g. Evers and Seidel, 2005) it is probably wise to restrict collecting this species at Nassau to clearly specified research objectives and under strict conditions (catch quota).

DISCUSSION

We can compare the results of our inventory of the fish fauna of Lely and Nassau Mountains with fish faunas of other mountains in Suriname and Guyana. Data are available for Tafelberg Mountain (Ouboter 2003, P.E. Ouboter pers. communication), Brownsberg Mountain (Mol, personal observations), Bakhuis Mountains (Mol, unpublished results) and, in Guyana, the highlands of the plateau above Kaieteur Falls (Eigenmann 1912). The low number of fish species in the high-altitude streams of Lely and Nassau Mountains reflects the high altitude of the streams. High-altitude streams in Tafelberg (1026 m.amsl) and Brownsberg (514 m.amsl) Mountains also had few fish species, i.e. two species at Tafelberg (*Rivulus amphoreus* and *Erythrinus erythrinus*); and three species at Brownsberg above Koemboe Falls (*Lithoxus surinamensis*, a trichomycterid catfish and an unidentified loricariid catfish; J. Mol and P.E. Ouboter, unpublished results). Small streams in Bakhuis Mountains had more species (about 10-20), but the altitude of the collection sites in Bakhuis Mountains was much lower (<250 m.amsl) than in Lely and Nassau Mountains. In the large Potaro River, Guyana, Eigenmann (1912) recorded 140 fish species below Kaieteur Falls (or 76 species when excluding species of the Essequibo River) and only 23 species on the plateau above the falls (including *C. callichthys*, *Trichomycterus guianensis*, and *Rivulus holmiae*). Eigenmann (1912) collected 5 (22%) new, endemic fish species above Kaieteur Falls, including *Lithogenes villosus*, a peculiar loricariid catfish with its armor reduced to a few ossicles. As expected, the lowland stream in the foot hills of Nassau Mountains had a much larger number of fish species.

It is difficult to estimate how many species occur in the high-altitude streams of Nassau Mountains. Species collected in Nassau Mountains by Geijskens and Creutzberg in 1949 (Appendix 10) and not collected by us during the present RAP expedition are all lowland species (i.e. they were collected at low altitude in the foot hills of Nassau Mountains, not on the plateau). However, our second survey in 2006 added 5 species to the 6 species collected in the high-altitude IJskreek tributary of Paramaka Creek during the RAP survey of November 2005. We think that continued sampling in additional streams and at sites located more downstream from present collection sites would add species to the total. We estimate that at least 15 species occur in the high-altitude streams of Nassau Plateau.

High-altitude streams in both Lely and Nassau Mountains had few species, but the streams of Nassau Plateau had 6 species that are potentially new to science and that potentially have their distribution restricted to the Nassau Plateau (e.g. *H. crassicauda*, *Guyanancistrus* 'big mouth', *Trichomycterus* aff *conradi* and three *Lithoxus* species) while Lely Mountains had none. The reasons for this large difference in endemism are not clear and should be investigated in the future. Some species (e.g. *H. crassicauda* and *Guyanancistrus* 'big mouth') from high-altitude streams of Nassau Mountains are apparently restricted to this small 20x20 km^2 area; with other species endemism has to be established with future collection efforts (*Lithoxus* spp, *Trichomycterus* aff *conradi*). The distribution of some fish species was apparently restricted to high-altitude reaches of a single stream (*H. crassicauda* in Paramaka Creek) or even a tributary of a stream (*Guyanancistrus*-'big mouth' and the slender form of *H. crassicauda* in the northern tributary of Paramaka Creek). The steep slopes of the Nassau Mountains plateau probably are a biogeographic barrier preventing the dispersal of fishes throughout the mountains/plateau.

A striking aspect of the fish communities of the high-altitude streams of Nassau and Lely Mountains is the large number of small-sized species. Although not miniature species according to the criteria of Weitzman and Vari (1988; i.e. species not exceeding 2.6 cm SL), many species of Lely and Nassau Mountains can be considered dwarf species, e.g. *Lithoxus* spp, *H. crassicauda*, *Guyanancistrus* 'big mouth'. Whereas *Harttiella crassicauda* (with 5 cm TL the smallest Loricariinae species) can be considered a derived, dwarf-form of *Harttia*, 'big mouth' can be seen as a dwarf-form of *Guyanancistrus* (the hypothesized relationship of 'big mouth' with *Guyanancistrus* still has to be confirmed by DNA analysis in progress). Both *Harttia* (*H. surinamensis* and *H. guianensis*) and *Guyanancistrus* (*brevispinnis*) are known to occur in the Marowijne and Suriname rivers (Le Bail et al. 2000; Mol et al. in prep). *Lithoxus* are small-sized loricariid catfishes with a restricted geographical distribution endemic to the Guayana Shield (Boeseman 1982, Nijssen and Isbrücker 1990). The occurrence of dwarf species in high-altitude streams may be explained by poor food supply (as indicated by low nutrient concentrations; Table 9.1) or the small size of habitats in these shallow, high-altitude streams. Weitzman and Vari (1988) noted that, with the exception of one pimelodid and some trichomycterid catfish, all 85 miniatures they studied occurred in lentic or slow-flowing, shallow waters, a feature they attributed to the difficulties small fishes have in maintaining position in strong currents. The present collection of several dwarf catfishes from high-altitude streams with strong currents (up to 70 cm/s; Appendix 14) in Nassau Mountains shows that benthocryptic dwarf species actually do occur in fast flowing waters. Although most velocity measurements in IJskreek revealed strong currents, we also detected many spots with counter-currents or still water (e.g. behind boulders) where fishes could 'rest' out of the main current (Appendix 14).

Streams in Lely and Nassau Mountains typically have a sandy, gravel or rocky bottom and oxygen-rich, very clear water (Secchi transparency > 1.5 m; Table 9.1) and the fishes are adapted to these environmental conditions. Mining, which physically disturbs soils and potentially exposes soil to rainfall and thus erosion, has the potential to release fine sediments into streams, increasing the turbidity (suspended sediment concentrations) and depositing a layer of fine sediments (sedimentation) on the streambed and associated structures (rock, woody debris, leaf litter), thus altering the instream habitat of the fishes. Suspended sediment can reduce penetration of sunlight and thus photosynthesis and phytoplankton (algal) growth, while deposited sediment can smother filamentous algae (both diatoms and filamentous algae are major food items in the diet of *H. crassicauda*). Podostemaceae beds in rapids and their associated fish species (and aquatic invertebrates) were also vulnerable to sedimentation (Odinetz Collart et al. 1996). Suspended and deposited sediments can also negatively affect fish reproduction, e.g. by damaging or smothering fish eggs/embryos (Alabaster and Lloyd 1980). Mol and Ouboter (2004) showed that a Surinamese lowland rainforest stream affected by mining-related erosion had low fish species diversity, low proportion of young fishes, high proportion of midchannel surface-feeding fishes (e.g., hatchet fish *Gasteropelecus*) and fishes adapted to low light (e.g., gymnotoids and some catfishes), low proportion of visually-oriented fishes (e.g., cichlids) and fishes that hide in leaf litter and woody debris, and low biomass of food fishes. Many of the fish species of Lely and Nassau Mountains are probably feeding on aufwuchs algae (*H. crassicauda*, *Lithoxus* spp, *G. brevispinnis*, and 'big mouth') and are commonly found over rocks and clean sandy bottoms in clear water. These species would be particularly sensitive to the negative impacts of increased sediment loads.

There is no fishing in the high-altitude streams of Lely and Nassau Mountains; these streams mainly have small-sized species and only 'platkop kwikwi' (*C. callichthys*) of IJskreek can be considered a food fish. Streams in the foot hills of the mountains (e.g. Anjumara Creek, N3) have large-sized fishes (e.g. Anjumara *Hoplias aimara*) and are fished occasionally by Maroons living in the villages of Langatabbetje, Nason and Stoelmanseiland along Marowijne River and small-scale gold miners working in the area. Subsistence and artisanal fishery in lowland tributaries of Marowijne River by Maroons is not a special profession, but rather a part-time activity of vital interest. The Maroons use both traditional methods like hook-and-line, bow-and-arrow, fish traps (Surinamese baskita or maswa), and fish poisons (Surinamese neku, toxic substance is rotenone from the liana *Lonchocarpus* spp.), and modern gill nets. Target food fishes are anjumara (*Hoplias aimara*), patakka (*Hoplias malabaricus*), tukunari (*Cichla ocellaris*), kubi (*Plagioscion* spp.), piren (*Serrasalmus rhombeus* and *S. eigenmanni*), paku/pakusi (*Myleus rubripinnis* and *M. ternetzi*), kumaru (*Myleus rhomboidalis*), moroko (*Brycon falcatus*), sardine (*Triportheus brachipomus*), kwimata (*Prochilodus rubrotaeniatus*), waraku (*Leporinus* spp.), prake or stroomfisi (*Electrophorus electricus*), spikrikati (*Pseudoplatystoma* spp.), plarplari (*Ageneiosus* spp.), kwikwi (*Megalechis thoracata* and *Callichthys callichthys*), krobia (Cichlidae spp.), and other species. The majority of the catch is consumed fresh, but considerable quantities are also salted, dried, and smoked for preservation. Some are transported to Paramaribo.

The lowland streams in the foot hills of Lely and Nassau Mountains have many species that are well-known to ornamental fish hobbyists: pencil fish *Nannostomus bifasciatus*, splashing tetras *Copella carsevennensis* and *Pyrrhulina* *filamentosa*, dwarf-cichlid *Nannacara anomala*, leaf fish *Polycentrus schomburgkii*, and *Moenkhausia hemigrammoides*, *Steindachnerina varii*, *Helogenes marmoratus*, (Appendix 11) and *Leporinus* spp, *Hemigrammus unilineatus*, *Hemibrycon surinamensis* (Appendix 10). The high-altitude streams of Lely and Nassau Mountains also have several small-sized fish species of potential interest to ornamental fish hobbyists. These potential 'aquarium species' include two *Rivulus* species, *Ancistrus temminckii*, *Guyanancistrus brevispinnis*, *Lithoxus* spp, *Harttiella crassicauda*, and 'big mouth'. However, because some species of Nassau Mountains have a very restricted distribution (i.e. *H. crassicauda* and 'big mouth' apparently restricted to Nassau Plateau) and the distribution of other species is not well understood (*Lithoxus* spp), collection and export of fishes from high-altitude streams in Nassau Mountains for use as ornamental (aquarium) fishes should be prohibited.

ENVIRONMENTAL ISSUES AND CONSERVATION RECOMMENDATIONS

Lely and Nassau Mountains are concessions of the joint venture Suralco(Alcoa)/BHP-Billiton bauxite mining companies. Suralco is also involved in large-scale gold exploration by Newmont in the foot hills of Nassau Mountains. Both Nassau and Lely Mountains are key components of a larger, international protection plan for the Guayana Shield (Huber and Foster 2003). Our fish survey shows that the watersheds on the plateau are largely intact in both Lely and Nassau Mountains. However, in both Lely and Nassau Mountains, human activities (gold mining, logging, agriculture, hunting) threaten the integrity of the aquatic ecosystems in the foot hills. Considerable effects of human activities (e.g. sedimentation in streams, deforestation) were observed in the northern foot hills of Nassau Mountains.

We encountered no exotic or invasive fish species in the streams of Nassau and Lely Mountains. The current abundance of fishes and excellent condition of the fish fauna in the high-altitude streams in Nassau and Lely Mountains is dependent upon the preservation of the healthy and pristine condition of the watersheds, especially the upper catchment of the head waters on the plateau. Mining of the plateau would potentially expose these head water streams with clear water to sediments re-worked by mining and change the structure of the fish communities (e.g. Mol and Ouboter 2004). For example, the endemic catfish *Harttiella crassicauda* would be affected by (1) food supply (turbidity and sedimentation negatively affect stream algae) and (2) reproduction (smothering and/or abrasion of eggs and larvae).

High-altitude streams in Lely Mountains offer excellent opportunities for conservation because human population densities in the area are low and, consequently, human impact on the aquatic ecosystems is also low. However, fish species diversity and endemism is low. The remoteness of Lely Mountains adds to its importance as a conservation area.

Fish diversity of high-altitude streams in Nassau Mountains is also low, but conservation of these streams is extremely important due to the occurrence of unique species like *Harttiella crassicauda* and *Guyanancistrus* 'big mouth'. The endemic catfish *H. crassicauda* has an extremely restricted geographic distribution: it probably occurs in only one high-altitude stream in the 20x20 km^2 area of Nassau Mountains. At present its occurrence has been proved only for two tributaries of Paramaka Creek at 370-535 m.amsl altitude, notwithstanding considerable collection effort in both Suriname (Ouboter and Mol 1993) and French Guiana (Le Bail et al. 2000). Because most fish species of high-altitude streams of Nassau Mountains are probably not widely distributed and some species may be endemic to Nassau Mountains (e.g. *Harttiella crassicauda*, *Guyanancistrus* 'big mouth') we agree with Sheldon (1988) that conservation efforts should focus on the largest natural drainages as possible (i.e. the entire watershed of the streams draining Nassau Mountains). In other words, ecosystem management as opposed to species management. Activities that cause erosion, turbidity, sedimentation, changes to the natural hydrological cycle of the streams (e.g. deforestation), and/or pollution, have the capacity to diminish forever (1) the pristine character and biological value of streams in Nassau Mountains and (2) opportunities for studies into ecological and evolutionary processes that shaped the unique fish fauna of the mountains. Such activities that lead to degradation of the pristine environmental conditions must be prevented.

Although opportunities for conservation of Nassau Mountains are good, the potential threat of human impact is growing. Threats include not only bauxite and gold mining, but also forestry, tourism, and unregulated hunting. Most of the unique fish species of the plateau of Nassau Mountains were collected in Paramaka Creek and the upper catchment of this stream should be protected carefully (e.g. entrance to the concession should be strictly controlled by the mining companies Suralco/BHP-Billiton or Surinamese Government). Additional surveys of both lowland streams in the foot hills (especially Paramaka Creek) and high-altitude streams on the plateau of Nassau (and Lely) Mountains are needed to better understand (1) the ecology and evolution of the unique fish communities of the plateau and (2) diversity and endemism of Guayana Shield fish faunas in general. Continuing work is also required to confirm the taxonomy of a further six species collected in Nassau Mountains. Actions should be taken to submit *Harttiella crassicauda* for inclusion in IUCN red list of endangered species. A great responsibility is in the hands of the Surinamese government, concession holder Suralco/BHP Billiton and NGOs like Conservation International and WWF.

The flora and fauna of Nassau Mountains is very fragile; we recommend that Nassau Mountains is declared a protected area (nature reserve). In a corridor outside the reserve, forestry and mining should be prohibited and hunting (and fishing) regulated and monitored carefully, involving local people in setting regulations or limits. Hunting and fishing (including the collection of aquarium fishes) should be prohibited in the reserve. Ecotourism is excellent for developing public awareness and appreciation of Nassau Mountains, but it can also easily have a negative impact because of the fragility of the ecosystems of Nassau Mountains. A tourist camp should be constructed outside the Paramaka Creek watershed and camping should be restricted to this site. A small exhibition building with posters and aquariums should be set up at the tourist camp to inform visitors of the species and ecosystems of Nassau Mountains. Trails should be plotted in the mountains (comparable to Brownsberg Mountains). Bathing in Paramaka Creek should be prohibited. All tourism should be regulated and monitored.

In conclusion, the pristine character of the Nassau and Lely Mountains should be carefully protected, since the unique fish faunas of the mountains evoke questions related to ecological/evolutionary processes that may explain the origin of fish diversity in the Guayana Shield region.

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Appendix 10

Fishes collected in Nassau Mountains in 1949 by D.C. Geijskens and P.H. Creutzberg (Boeseman 1953).

Jan H. Mol, Kenneth Wan Tong You, Ingrid Vrede, Adrian Flynn, Paul Ouboter and Frank van der Lugt

Taxa	Number of specimens	Remarks
Characiformes		
Anostomidae		
Leporinus granti Eigenmann 1912	6	lowland streams
Leporinus fasciatus (Bloch 1795)	1	lowland streams & rivers
Characidae		
Astyanax bimaculatus (L. 1758)	4	lowland streams
Hemibrycon surinamensis Gery 1962	8	mountain streams? (Géry 1962)
Hemigrammus unilineatus Gill 1858	4	lowland streams
Jupiaba abramoides (Eigenmann 1909)	4	lowland streams
Erythrinidae		
Erythrinus erythrinus (Bloch & Schneider 1801)	4	lowland streams
Lebiasinidae		
Pyrrhulina filamentosa Val. 1846	60	lowland streams
Prochilodontidae		
Prochilodus rubrotaeniatus Jardine & Schomburgk 1841	1	lowland rivers
Serrasalmidae		
Serrasalmus rhombeus L. 1766	3	lowland streams & rivers
Siluriformes		
Callichthyidae		
Megalechis thoracata (Val. 1840)	11	lowland streams
Cetopsidae		
Helogenes marmoratus Günther 1863	7	lowland streams
Doradidae		
Platydoras costatus (L. 1758)	2	lowland streams & rivers
Heptapteridae		
Chasmocranus brevior Eigenmann 1912	3	known only from Nassau & Potaro River, Guyana (Mees 1974)
Heptapterus bleekeri Boeseman 1953	9	known also from Suriname River & Amapa, Brazil (Mees 1974)
Rhamdia quelen (Quoy & Gaimard 1824)	7	lowland streams

Taxa	Number of specimens	Remarks
Loricariidae		
Harttiella crassicauda (Boeseman 1953)	15	endemic to Nassau Mountains
Pimelodidae		
Pimelodus ornatus Kner 1858	1	lowland streams & rivers
Trichomycteridae		
Trichomycterus guianensis (Eigenmann 1909)	26	identification correct?
Total = 19 species	**176**	

Appendix 11

Fishes collected during the November 2005 RAP expedition to the Lely and Nassau plateaus, Suriname.

Jan H. Mol, Kenneth Wan Tong You, and Ingrid Vrede

Collections were made in four mountain streams in the Lely Mountains (L1-L4) and one mountain stream (N1), one lowland stream (N3) and one high-altitude-depression palm swamp (N2) in the Nassau Mountains.

Taxa	Lely Mountains				Nassau Mountains			Number of Specimens
	L1	L2	L3	L4	N1	N2	N3	
CHARACIFORMES								
Characidae								
Acestrorhynchus sp. (juvenile)							●	1
Bryconops affinis							●	1
Hemigrammus cf *rodwayi*							●	10
Jupiaba abramoides							●	1
Moenkhausia chrysargyrea							●	25
Moenkhausia hemigrammoides							●	7
Crenuchidae								
Microcharacidium eleotrioides							●	2
Curimatidae								
Steindachnerina varii							●	2
Erythrinidae								
Erythrinus erythrinus							●	2
Hoplias aimara							●	3
Hoplias malabaricus							●	5
Lebiasinidae								
Copella carsevennensis							●	2
Nannostomus bifasciatus							●	17
Pyrrhulina filamentosa							●	11
SILURIFORMES								
Callichthyidae								
Callichthys callichthys					●			10
Megalechis thoracata [1]							●	1
Cetopsidae								
Helogenes marmoratus							●	5

Taxa	Lely Mountains				Nassau Mountains			Number of Specimens
	L1	L2	L3	L4	N1	N2	N3	
Loricariidae								
Ancistrus temminckii		●						2
Ancistrus cf *temminckii*		●						28
Guyanancistrus brevispinnis		●						13
Harttiella crassicauda					●			50
Lithoxus sp.1					●			7
Lithoxus surinamensis		●						14
Trichomycteridae								
Ituglanis cf *amazonicus*		●						39
Trichomycterus aff *conradi*					●			45
GYMNOTIFORMES								
Gymnotidae								
Gymnotus carapo							●	1
Gymnotus coropinae							●	24
Hypopomidae								
Hypopygus lepturus							●	5
CYPRINODONTIFORMES								
Rivulidae								
Rivulus cf. *igneus*	●	●	●		●	●	●	286
Rivulus cf. *lungi*	●	●		●				98
SYNBRANCHIFORMES								
Synbranchidae								
Synbranchus marmoratus	●		●		●		●	10
PERCIFORMES								
Cichlidae								
Crenicichla saxatilis							●	1
Guianacara owroewefi							●	4
Krobia guianensis							●	21
Nannacara anomala							●	7
Nandidae								
Polycentrus schomburgkii							●	27
Total = 36 species	**3**	**7**	**2**	**1**	**6**	**1**	**26**	**787**

[1] see Reis et al. 2005

Appendix 12

Phytoplankton and periphyton of Paramaka Creek headwaters (IJskreek; altitude 300-530 m.amsl).

Jan H. Mol and Asha Haripersad-Makhanlal

Periphyton (5 samples of tufts of filamentous algae attached to boulders) were collected on November 5, 2005. Phytoplankton (5 samples of 1 L) were collected from March 30 – April 3, 2006; three out of 5 samples had no algae. Analyses were done by Asha Haripersad-Makhanlal, Hydraulic Research Division (WLA), Ministry of Public Works, Paramaribo.

Taxa	Periphyton Abundance	Phytoplankton Abundance (individuals/L)
Filamentous Rhodophyta (red algae)		
Batrachospermum cf. *cayenense*	Dominant	
Batrachospermum sp.	Abundant	
?Hildenbrandia sp.	Rare	
Rhodophyta sp.	Rare	
Filamentous Chlorophyta (green algae)		
Chaetophora cf *attennuata*	Rare	
Spirogyra sp.	Locally abundant	0-5
Diatomae		
Eunotia spp.	Abundant (on branches of *Batrachospermum*)	0-5
Navicula sp.	5 specimens	0-5
Desmidiaceae		
Cosmarium sp.	1 specimen	
Closterium sp.		0-5
Miscellaneous		
Bacteria	In one sample	
Rhizopoda	Rare	
Rotifera (*Lecane* sp.)	1 specimen	

Appendix 13

Fishes collected in high-altitude (plateau) streams of the Nassau Mountains from March 29 – April 4, 2006.

Jan Mol, Kenneth Wan Tong You, and Ingrid Vrede

Paramaka Creek was sampled in the central branch (IJskreek) up- and downstream (N1) of the BHP camp, and in a northern and southern tributary (tributaries joined the central branch in the foot hills).

Taxa	Paramaka Creek				Other streams on the plateau			Number of specimens
	central tributary upstream BHP camp	central tributary downstream BHP camp	northern tributary Na3	southern tributary Na5	unnamedsouthern stream Na6	unnamedsouthern stream Na4	unnamednorthern stream Na2	
SILURIFORMES								
Callichthyidae								
Callichthys callichthys	●							3
Loricariidae								
Ancistrus sp.							●	1
Guyanancistrus sp. 'big mouth'			●					15
Harttiella crassicauda		●						40
Harttiella cf. *crassicauda*			●					40
Lithoxus sp.1		●				●	●	7
Lithoxus sp.2 (forked caudal)		●						1+
Lithoxus sp.3 (light spots)				●				1+
Trichomycteridae								
Trichomycterus aff *conradi*		●		●	●	●	●	20
CYPRINODONTIFORMES								
Rivulidae								
Rivulus cf. *igneus*	●	●		●		●		47
SYNBRANCHIFORMES								
Synbranchidae								
Synbranchus marmoratus			●		●		●	3
Total = 11 species	**2**	**5**	**3**	**3**	**2**	**3**	**4**	**178**

Appendix 14

Habitat structure of a high-altitude reach of Paramaka Creek (IJskreek, 460 m.amsl; site N1), Nassau Mountains, where *Harttiella crassicauda* was collected.

Jan H. Mol, Kenneth Wan Tong You, and Ingrid Vrede

N = 40 point samples. Date of measurements was March 31, 2006. Habitat diversity (Gorman and Karr 1978) was calculated for each dimension alone and then for the combination of depth, current, and substrate type with the Shannon-Wiener index (*H*). $H = - \Sigma (pi * \ln (pi))$, where *pi* is the proportion of point samples in the *i*th category.

Variable/category	Proportion (pi)	Diversity (H)
Water depth (cm)		1.275
0-10	0.150	
11-20	0.450	
21-30	0.250	
>30	0.150	
Current (cm/second)		1.767
0-10	0.175	
11-20	0.125	
21-30	0.200	
31-40	0.150	
41-50	0.225	
51-70	0.125	
Substrate type		1.527
Silt (diameter <0.05 mm)	0	
Sand (0.05-2 mm)	0	
Gravel (2-10 mm)	0.375	
Pebbles (10-30 mm)	0.125	
Boulder (>30 mm)	0.200	
Bedrock	0.235	
Leaf litter	0.025	
Woody debris	0	
Tree roots	0.050	
Aquatic macrophytes	0	
Water depth x current x substrate		3.295

Appendix 15

Observations on the behavior of *Harttiella crassicauda* and *Guyanancistrus* n.sp. ('big mouth') of Nassau Mountains in the aquarium.

Kenneth Wan Tong You

Transportation of *Harttiella crassicauda* from Nassau Mountains to Paramaribo proved difficult: in November 2005 only two out of ten specimens survived the 7-hour drive over roads that were in bad condition and partially unpaved. With special precautions (battery-powered air pumps, low density of fishes, transport containers with thermal isolation against over heating) survival during transportation was much better after the survey of March/April 2006 (estimated survival 80%).

The two *Harttiella* specimens (including a 5.5-cm Total Length male with enlarged pectoral spines) from the November-survey were transferred to a large (90x40x40 (height) cm) aquarium with gravelly substrate, dense vegetation of submersed aquatic macrophytes (Vallisneria, Cryptocoryne, Echinodorus, Cabomba) and woody debris from IJskreek for shelter. Other fishes in the tank included *Apistogramma steindachneri*, *Lithoxus* cf *bovalli*, *Chasmocranus longior*, *Parotocinclus britskii*, and some small-sized poeciliids. Tank water was filtered by two 3-5 W air pumps. Light was provided by a 20 W neon lamp. The two *Harttiella* specimens were only active during the night, possibly related to activity of other fishes in the aquarium (see below). *Harttiella* was not very active in the aquarium, staying at one spot for long times. The male was territorial, defending its shelter against intruders (e.g. *Lithoxus*). Otherwise, *Harttiella* is a peaceful fish not bothering other fishes (conspecifics or other species). At night they spend most time grazing periphyton algae on the aquarium panes, macrophytes leaves and woody debris.

In the period November 2005 – March 2006, the male increased about 0.5 cm in length. In April, I obtained four additional *Harttiella* specimens from Nassau Mountains (second population from the northern tributary of Paramaka Creek) together with four specimens of a new loricariid catfish *Guyanancistrus* 'big mouth'. These eight fishes were transferred to a small aquarium (37x23x22 (height) cm) with a battery-powered air pump, fine sandy substrate, no aquatic macrophytes, some rock (shelter) and no other fishes in the tank. The aquarium received indirect sun light to stimulate algal growth. At one occasion I observed that *Harttiella* specimens buried themselves in the sand (note that the northern tributary of Paramaka Creek had sand substrate at some sites, contrary to the central branch of Paramaka Creek (IJskreek) with substrate that consisted of gravel, pebbles and boulders). I also observed that *Harttiella* were active during the day in this tank. At times they moved to the water surface near the outlet of the air pump (in the water current) where they lifted their head partially out of the water to graze on algae.

In conclusion, I find *Harttiella* a sensitive species that does not accept artificial aquarium feeds (e.g. flakes and tablet feeds), but feeds exclusively on algae. Therefore it is important to stimulate growth of algae in the aquarium. They are easily disturbed by other tank mates with the result that they retreat in shelter during the day. They are also easily stressed when deprived of shelter. *Harttiella* seems to prefer fresh, clear water with neutral pH and high dissolved oxygen concentration, and possibly a low water temperature (20-24 ^{o}C) like observed in its natural habitat, the high-altitude IJskreek (500 m.amsl).

Guyanancistrus 'big mouth' of the northern branch of Paramaka Creek was active both during the day and at night. This species did not retreat in shelter (including one specimen that was transferred to the large aquarium with numerous other fishes). 'Big mouth' was not territorial, tolerating the presence of conspecifics and other species. 'Big mouth' preferred to stay in the water flow near the outlet of the air pump where they were observed feeding on algae and flakes with their head partially lifted out of the water. They did not spend much time on the bottom, but were mainly observed grazing algae on the aquarium panes, macrophytes, woody debris and rock. After a short acclimation time 'Big mouth' accepted vegetarian flakes.