

CHARACTERIZATION OF 10 MICROSATELLITE LOCI FOR *BATHYSA AUSTRALIS* (RUBIACEAE)¹

TALITA S. REIS^{2,6}, MAÍSA CIAMPI-GUILLARDI^{3,4}, CRISTINA BALDAUF⁵, ANETE P. SOUZA^{2,3},
AND FLAVIO A. M. DOS SANTOS²

²Departamento de Biologia Vegetal, Instituto de Biologia, Universidade Estadual de Campinas, P.O. Box 6109, 13083-970 Campinas, São Paulo, Brazil; ³Centro de Biologia Molecular e Engenharia Genética, Universidade Estadual de Campinas, P.O. Box 6010, 13083-875 Campinas, São Paulo, Brazil; ⁴Departamento de Fitopatologia, Escola Superior de Agricultura “Luiz de Queiroz” (ESALQ)/Universidade de São Paulo, 12418-900 Piracicaba, São Paulo, Brazil; and ⁵Universidade Federal Rural do Semiárido, 59625-900 Mossoró, Rio Grande do Norte, Brazil

- *Premise of the study:* *Bathysa australis* is a common subcanopy tree from the Atlantic Forest that is pollinated by bees and wasps and produces autochoric seeds. This species exhibits great phenotypic plasticity along the elevational gradient of Serra do Mar in southeastern Brazil. We expect to assess the genetic diversity and gene flow between populations of this species along the elevational gradient.
- *Methods and Results:* We developed a microsatellite-enriched genomic library for *B. australis*, and 10 microsatellite loci were successfully amplified, ranging from one to 13 alleles per locus. The observed and expected heterozygosities ranged from 0.333 to 0.900 (average: 0.629) and 0.564 to 0.900 (average: 0.742), respectively.
- *Conclusions:* These are the first microsatellite markers developed for the genus *Bathysa* and may be useful in other species of the Condamineae tribe. These primers will be an important tool for studies of population ecology and conservation genetics.

Key words: Atlantic Forest; *Bathysa australis*; conservation genetics; medicinal plant; polymorphism; population ecology.

Bathysa australis (A. St.-Hil.) Hook. f. ex K. Schum. (Rubiaceae) is a subcanopy tree that is widespread along the elevational gradient (100–1000 m a.s.l.) of the Atlantic Forest of Serra do Mar in São Paulo State, Brazil. This species is a common plant in parts of the Atlantic Forest (e.g., Ramos et al., 2011) and has an important role in ecosystem functioning, e.g., providing a nectar source to a variety of insects (Andrich, 2008). Furthermore, its bark is used in folk medicine (Germano-Filho, 1999), which indicates its social value in addition to its ecological value. *Bathysa australis* displays great phenotypic plasticity in leaf size and color along its elevational gradient, is pollinated mainly by bees and wasps (Andrich, 2008), and presents autochoric seed dispersal (Pedroni, 2001). Because we believe the elevational gradient might function as a barrier for *B. australis* gene flow, the investigation of the spatial distribution of the dispersal, pollination, and genetic diversity of this plant could generate important information regarding its population biology. Above all, the Brazilian Atlantic Forest is significantly threatened (Myers et al., 2000), and the microsatellites developed in this study should serve as tools to evaluate the impacts and define conservation strategies.

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⁶Author for correspondence: talitasr@gmail.com

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METHODS AND RESULTS

We extracted genomic DNA from leaf tissue samples using the DNeasy Plant Mini Kit (QIAGEN, Valencia, California, USA). A microsatellite-enriched library was then developed following Billotte et al. (1999). The DNA samples were digested using the *RsaI* restriction enzyme (Invitrogen, Carlsbad, California, USA) for 3 h at 37°C, and the resulting fragments were ligated to *RsaI* adapters for 2 h at 20°C. The fragments containing microsatellites were selected by hybridization with (CT)₈- and (GT)₈-biotinylated oligonucleotides, followed by capture with Streptavidin MagneSphere Paramagnetic Particles (Promega Corporation, Fitchburg, Wisconsin, USA). The selected DNA fragments were PCR-amplified in a final volume of 100 µL containing 20 µL of selected fragments, 1× PCR buffer, 1.5 mM MgCl₂, 200 µM dNTPs, 4 pmol of primer Rsa21, and 2.5 U of *Taq* DNA polymerase. A PTC-100 thermal cycler (MJ Research, Waltham, Massachusetts, USA) was used with the following program: 95°C for 1 min, followed by 25 cycles of denaturation at 94°C for 40 s, 60°C for 1 min, extension of 72°C for 2 min, and a final extension of 72°C for 5 min. The amplification products were cloned into the pGEM-T Easy Vector (Promega Corporation). Plasmids were transformed into *Escherichia coli* XL1-Blue competent cells, and positive clones were selected using the β-galactosidase gene and grown overnight in an HM/FM medium with ampicillin. A total of 96 positive clones were bidirectionally sequenced using an automated ABI PRISM 377 sequencer (Applied Biosystems, Foster City, California, USA) with T7 and SP6 primers and the BigDye Terminator version 3.1 Cycle Sequencing Kit (Applied Biosystems). The sequences were assembled and edited using SeqMan Pro (DNASTar Inc., Madison, Wisconsin, USA). The repetitive regions were identified using the Simple Sequence Repeat Identification Tool (Temnykh et al., 2001), and 30 primer pairs were designed using WebSat (Martins et al., 2009). Ten primer pairs amplified microsatellite regions and were selected for screening (Table 1). The remaining loci were discarded due to amplification failures or nonspecific amplification patterns. The forward primer for each pair was labeled with fluorochromes (HEX and TET).

PCR amplifications were performed in a 15-µL volume containing 15 ng DNA, 1× PCR buffer, 0.15 mM each dNTP, 0.8 mM each primer, 0.04% bovine serum albumin (BSA), 1.5 mM MgCl₂, and 1 U *Taq* DNA polymerase. A PTC-100 thermal cycler (MJ Research) was used with the following program: 96°C for

TABLE 1. Characteristics of 10 microsatellite markers developed for *Bathysa australis*.

Locus	Repeat motif	Primer sequences (5'–3')	T_a (°C)	Allele size range (bp)	GenBank accession no.
BA02	(CT) ₈	F: CTTGCCAAACTGAGCTTCTG R: GGTGATGGTGCTCCTCTTTC	62	150–180	KF267877
BA14	(TC) ₇	F: CAGCAAAGTCCACAGCACA R: TGCGTGCCAGTGTGAGT	62	140–200	KF267878
BA15	(CA) ₉	F: TCCCATTTTCCTGGTCGT R: TGGCATCCAAGACTCTGCTA	55	270–300	KF267879
BA16	(CA) ₁₁	F: TCACAGATCCTACAACAGCACC R: AGAAGGAGAACGCAAATACCC	55	190	KF267880
BA22	(AG) ₆	F: CCACAGGTTGTGTTTGTCTC R: GTCCCATTCCTTTCATATTCCA	55	330–360	KF267881
BA24	(GA) ₃₀	F: ACAGCGAAGTCCACACACAT R: TCTGTGGAAGAAGAGTGGGAAT	55	170–230	KF267882
BA25	(AC) ₄₀	F: TGCCAGTAAATAGGAGAGATTG R: TTATGCTGCTGGAATGGTATTG	55	150–180	KF267883
BA26	(CT) ₂₅	F: AGGTGCATTTGGAAGGTATTGA R: GTTTGAGGCTTTGGACATACATC	65	360–400	KF267884
BA28	(TG) ₇	F: AGGACTTCCATTTTGTGGGTA R: GGGTTTTAATTTTCGTGACTTGC	55	340–400	KF267885
BA30	(CT) ₃₃	F: CTTGAATGCTGCTGGTAAAGC R: GCATCCTTTTGGACTCAATTTTC	65	290–370	KF267886

Note: T_a = annealing temperature.

1 min, followed by 30 cycles of denaturation at 94°C for 1 min, 1 min at a specific annealing temperature (T_a), and a final extension of 72°C for 5 min. The obtained products were verified by electrophoresis on 3% agarose gels containing 0.1 mg ethidium bromide per milliliter in 1× TBE buffer and genotyped using 6% denaturing polyacrylamide gels dyed with silver nitrate (Creste et al., 2001). We estimated the allele sizes by comparison to a 10-bp DNA ladder (Invitrogen).

The amplicons were electrophoretically separated using an ABI 377 automated sequencer (Applied Biosystems) with GeneScan 500 TAMRA marker as the size standard (Applied Biosystems). The fragment size and allele identification were determined using GeneMarker version 2.2 software (SoftGenetics, State College, Pennsylvania, USA). Cross-species amplifications were evaluated using five other species from the Rubiaceae family with varying phylogenetic proximity to *B. australis*: *B. mendoncae* K. Schum., *B. stipulata* (Vell.) C. Presl, and *Rustia formosa* (Cham. & Schltdl.) Klotzsch (Condamineae tribe, Ixoroideae subfamily); *Rudgea jasminoides* (Cham.) Müll. Arg. (Psychotriaceae tribe); and *Coussarea accedens* Müll. Arg. (Coussareeae tribe, Rubioideae subfamily) (Bremer and Eriksson, 2009).

We characterized the preliminary genetic diversity of *B. australis* populations from lowland (20 individuals; 23.3762°S, 45.0806°W, Ubatuba, São Paulo, Brazil) and upland (20 individuals; 23.3259°S, 45.0710°W, São Luis do Paraitinga, São Paulo, Brazil) Serra do Mar. Descriptive statistics and Hardy–Weinberg equilibrium tests were performed using GenAIE version 6.5 (Peakall and Smouse, 2006). The same nine loci were polymorphic in both populations (Table 2) and for these the average number of alleles was 8.6, ranging from five to 13 alleles per locus. The observed and expected heterozygosities ranged from 0.333 to 0.900 (average: 0.629) and 0.564 to 0.900 (average: 0.742), respectively. The fixation index ranged from –0.089 to 0.611, with an average of 0.147. Four loci in the lower population and three loci in the upper population showed significant deviations from Hardy–Weinberg equilibrium ($P < 0.05$). These results indicated some slight excess of homozygotes, which might have resulted from mating between relatives and/or the inbreeding generated by selfing; *B. australis* is a self-compatible species (Andrich, 2008). All 10 loci amplified successfully in the other *Bathysa* C. Presl species, but only four primers performed well for *Rustia formosa* (Table 3); all primers failed for *Rudgea jasminoides* and *Coussarea accedens*.

TABLE 2. Results of initial primer screening of lower (23.3762°S, 45.0806°W) and upper (23.3259°S, 45.0710°W) *Bathysa australis* populations. Only polymorphic loci are shown.

Population	Locus	A	A_e	H_o	H_e	F	HWE ^a
Lower (N = 20)	BA02	5	2.417	0.450	0.601	0.232	ns
	BA14	12	5.270	0.842	0.832	–0.039	ns
	BA15	8	5.369	0.850	0.835	–0.045	ns
	BA22	5	2.222	0.500	0.564	0.091	ns
	BA24	12	2.462	0.500	0.609	0.158	*
	BA25	7	5.026	0.353	0.825	0.559	**
	BA26	11	8.163	0.600	0.900	0.316	ns
	BA28	8	5.755	0.900	0.847	–0.089	*
	BA30	12	6.968	0.333	0.881	0.611	**
	Upper (N = 20)	BA02	5	2.606	0.600	0.632	0.026
BA14		11	6.422	0.647	0.870	0.234	**
BA15		8	3.404	0.750	0.724	–0.062	ns
BA22		6	2.548	0.550	0.623	0.095	ns
BA24		11	4.938	0.800	0.818	–0.003	ns
BA25		7	4.040	0.750	0.772	0.003	ns
BA26		13	7.407	0.650	0.887	0.249	**
BA28		5	3.162	0.450	0.701	0.342	***
BA30		10	4.396	0.800	0.792	–0.036	ns

Note: A = number of alleles; A_e = effective number of alleles; F = fixation index; H_e = expected heterozygosity; H_o = observed heterozygosity; HWE = Hardy–Weinberg equilibrium tests; N = number of individuals sampled.

^aSignificant departures from HWE are indicated at the following levels: * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$; ns = nonsignificant.

TABLE 3. Results from the cross-amplification tests using primers designed for *Bathysa australis*.

Locus	<i>Bathysa stipulata</i>	<i>Bathysa mendoncae</i>	<i>Rustia formosa</i>	<i>Coussarea accedens</i>	<i>Rudgea jasminoides</i>
BA02	+	+	+	–	–
BA14	+	+	–	–	–
BA15	+	+	–	–	–
BA16	+	+	–	–	–
BA22	+	+	+	–	–
BA24	+	+	–	–	–
BA25	+	+	–	–	–
BA26	+	+	+	–	–
BA28	+	+	–	–	–
BA30	+	+	+	–	–

Note: + = successful amplification; – = failed amplification.

CONCLUSIONS

The microsatellite markers described here are the first developed for the genus *Bathysa* and will be useful for genetic, ecological, and conservation management evaluations. Cross-species amplifications suggest that some of these loci may be useful in other species from the tribe Condamineae (subfamily Ixoroideae).

LITERATURE CITED

ANDRICH, M. 2008. Sistema reprodutivo e polinização em duas espécies arbóreas simpátricas de *Bathysa* (Rubiaceae). Dissertation, Instituto de Pesquisas, Jardim Botânico do Rio de Janeiro/Escola Nacional de Botânica Tropical, Rio de Janeiro, Brazil.

BILLOTTE, N., P. J. R. LAGODA, A. M. RISTERUCCI, AND F. C. BAURENS. 1999. Microsatellite-enriched libraries: Applied methodology for

the development of SSR markers in tropical crops. *Fruits* 54: 277–288.

BREMER, B., AND T. ERIKSSON. 2009. Time tree of Rubiaceae: Phylogeny and dating the family, subfamilies, and tribes. *International Journal of Plant Sciences* 170: 766–793.

CRESTE, S., A. TULMANN NETO, AND A. FIGUEIRA. 2001. Detection of single sequence repeat polymorphisms in denaturing polyacrylamide sequencing gels by silver staining. *Plant Molecular Biology Reporter* 19: 299–306.

GERMANO-FILHO, P. 1999. Estudos taxonômicos do gênero *Bathysa* C.Presl (Rubiaceae, Rondeletieae), no Brasil. *Rodriguésia* 50: 49–75.

MARTINS, W. S., D. C. S. LUCAS, K. F. S. NEVES, AND D. J. BERTIOLI. 2009. WebSat: A Web software for microsatellite marker development. *Bioinformatics (Oxford, England)* 3: 282–283.

MYERS, N., R. A. MITTERMEIER, C. G. MITTERMEIER, G. A. B. FONSECA, AND J. KEN. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403: 853–858.

PEAKALL, R., AND P. E. SMOUSE. 2006. GenA1Ex 6: Genetic analysis in Excel. Population genetic software for teaching and research. *Molecular Ecology Notes* 6: 288–295.

PEDRONI, F. 2001. Aspectos da estrutura e dinâmica da comunidade arbórea na Mata Atlântica de planície e encosta em Picinguaba, Ubatuba, SP. Dissertation, Universidade Estadual de Campinas, Campinas, São Paulo, Brazil.

RAMOS, E., R. B. TORRES, R. F. A. VEIGA, AND C. A. JOLY. 2011. Estudo do componente arbóreo de dois trechos da Floresta Ombrófila Densa Submontana em Ubatuba (SP). *Biota Neotropica* 11(2): <http://www.biotaneotropica.org.br/v11n2/en/abstract?inventory+bn02411022011>.

TEMNYKH, S., G. DECLERCK, A. LUKASHOVA, L. LIPOVICH, S. CARTINHOUR, AND S. MCCOUCH. 2001. Computational and experimental analysis of microsatellites in rice (*Oryza sativa* L.): Frequency, length variation, transposon associations, and genetic marker potential. *Genome* 11: 1441–1452.

APPENDIX 1. Voucher information for species used in this study.

Species	Voucher specimen accession no.	Collection locality
<i>Bathysa australis</i> (A. St.-Hil.) Hook. f. ex K. Schum.	HRCB 60163	Rio Claro, SP
<i>Bathysa stipulata</i> (Vell.) C. Presl	HRCB 60107	Rio Claro, SP
<i>Bathysa mendoncae</i> K. Schum.	HRCB 59786	Rio Claro, SP
<i>Rustia formosa</i> (Cham. & Schltdl.) Klotzsch	HRCB 59785	Rio Claro, SP
<i>Coussarea accedens</i> Müll. Arg.	HRCB 59788	Rio Claro, SP
<i>Rudgea jasminoides</i> (Cham.) Müll. Arg.	IAC 49279	Campinas, SP

Note: HRCB = Herbário Rioclarense, Universidade Estadual Paulista, Rio Claro, São Paulo, Brazil; IAC = Herbarium of the Instituto Agronômico de Campinas, Campinas, São Paulo, Brazil; SP = São Paulo.