**Supplemental material for Prospects for freshwater turtle population recovery are catalysed by pan-Amazonian community-based management**

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**Supplemental Material** **A. Demographic model development.**

***Methods***

***Estimating demographic parameters.*** We explored population management scenarios for *P. unifilis* via a female-only, stage-based (eggs/hatchlings, early juvenile, late juvenile and adults) matrix population projection model. Model parameters were obtained from the scientific literature for fecundity (clutch size or average eggs per nest integrated with number of clutches produced annually), survival rates (for nest/hatchling, juvenile, adult stages), and age to sexual maturity (duration of the juvenile stage class) (Table A1). We avoided estimates derived from populations undergoing heavy exploitation and favored studies providing means rather than ranges. Vital rates estimates derived from studies of *P. unifilis* were prioritized for inclusion; however, given paucity of demographic data for turtles generally and for tropical species specifically, we included some estimates from congeners (other *Podocnemis* spp.) when not available for *P. unifilis.* In particularfates of turtles during the post-hatchling phase to early juvenile phase are very poorly known for all turtles (the “lost years”, sensu (Carr 1952)). Although Mogollones et al. (2010) did report a first year (egg and hatchling) survival rate for *P. expansa* of 0.58, this value is unlikely to be generally applicable based on what is known of this stage class for other aquatic turtles (see (Congdon et al. 1994; Congdon et al. 1993; Iverson 1991), particularly considering the hyperdiverse predator community (including myriad aquatic, terrestrial and aerial species) found around Amazon rivers. As such, we set this vital rate at a value generally typical of freshwater turtles, that is, 0.2 (Pike et al. 2008; Zimmer-Shaffer et al. 2014). Also lacking adult survival rates specifically for *P. unifilis* we substituted survival data for a class of adult *P. expansa* of comparable size to *P. unifilis* and juvenile survival for the comparably sized *P. vogli* (Table A1). Final estimates used for model parameters (Table A2) were based on grand means for parameters with multiple estimates and otherwise single estimates. Annual fecundity (F) was calculated as the product of clutch size and nesting frequency per year (lacking any data to the contrary, we assumed breeding frequency or proportion of females breeding annually was 100%) halved to reflect the females-only model assuming a 1:1 sex ratio for hatchlings.

***Model formulation****.* Our stage-structured matrix population model was based on annual increments (Caswell 2001). Matrix population model are adequate as both Amazon turtle life stages and the threats are readily discretized. There are four widely applied life stages (eggs, hatchlings, juveniles, adults) and threats also target specific stages (e.g. egg removal and hunting of nesting females). For juveniles, annual survival rates were prorated by duration of the juvenile stage to calculate both the probability of surviving and remaining in the stage (*P*i, as a function of *p*i = annual juvenile rate and *d*i duration of the juvenile stage, in years) and the probability of surviving while graduating to the adult stage (*G*i, also a function of *p*i and *d*i, see Crouse et al. (1987)). Mean duration of the juvenile stage was based on lowest value of the range (5-9 years) provided by (Thorbjarnarson et al. 1993) for *P. unifilis*, i.e., 5 years, because age at maturity for the much larger *P. expansa* has been authoritatively estimated at 4-5 years (Chinsamy and Valenzuela 2008), implying 9 years for *P. unifilis* would be atypical.

***Population projection****.* Population growth of *P. unifilis* was modelled by developing a 4x4 “Lefkovitch” stage-based matrix model for adults and juveniles (Lefkovitch 1965) (Table 3). Population diagnostics, including population growth sensitivity to change in individual population parameters, elasticities (proportional sensitivities), stable distributions of individuals amongst stage classes, and potential growth rates (λ) were determined with functions available in the R (R Development Core Team 2017) packages “popdemo” (Stott et al. 2016) and “popbio” (Stubben and Milligan 2007). Popdemo was also used to project populations 50 years into the future based on an initial population abundance vector of assuming 1000 adult females based on densities of 10 nests per km of river (Hernández et al. 2010) scaled up to represent our 100 km-long study area, and a complementary number of eggs and juveniles proportion to the stable stage distribution, providing a total of 18100 individuals across all stages at time zero.

We invoked the base model to evaluate plausible scenarios representing different population growth situations for *P. unifilis* (Table 3): 1) without harvest, 2) with destruction of nesting areas (rendering hatching success = 0 or the current situation in order to estimate times to population collapse), 3) with nest site protection (under consideration by local community, targeting a doubling of first year survival through egg translocation and single-year-long head-starting otherwise parameters held constant), and 4) killing of nesting females (reflected in a 10 - 50% decrease in annual survival rate, typical of what is occurring at present) combined with nest site protection (doubling of first year survival) in order to investigate outcomes of protecting nests while not addressing poaching of adults.

Table A1. Vital rates from studies of *Podocnemis unifilis* (and other *Podocnemis* spp.) used for estimating parameters of population projection models to explore population management scenarios. All survival rates are annual.

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Value | Location | Source |
| Clutches per year | 1 | Many locales | reviewed in Ojasti (1996), Vogt (2008) |
| Clutch size (number eggs) | 14 | Araguari River Basin, Brazil | Arraes and Tavares-Dias (2014) |
| 20.1 | Nichare-Tawadu Rivers, Venezuela | Escalona and Fa (1998) |
|  | 13.6 | Javaes River, Brazil | Ferreira and Castro (2010) |
|  | 12.7 | Javaes River, Brazil | Ferreira and Castro (2010) |
|  | 30.3 | Taboleiro da Água Preta, lower Amazon River, Brazil | Pignati et al. (2013) |
|  | 28.7 | Taboleiro da Água Preta, lower Amazon River, Brazil | Pignati et al. (2013) |
|  | 27.3 | Putomayo River, Columbia | Foote (1978) |
|  | 23 | Capanaparo River, Venezuela | Thorbjarnarson et al. (1993) |
|  | 7 - 52 | Many locales | Reviewed in Ojasti (1996) |
|  | 20 – 40 | Captive breeding | Gurley (2017) |
| Hatching success | 97% | Rio Purus, Brazil | Correa (1978) in Vanzolini (2003) |
|  | 78% | Iquitos area, Peru | Soini (1983) in Vanzolini (2003) |
|  | 97% | Rio Samiria, Loreto, Perú | Fachin (1993) in Vanzolini (2003) |
|  | 81%1 | Piagaçu Purus Sustainable Development Reserve, Amazon River, Brazil | Erickson and Baccaro (2016) |
| First year survival | 0.58 2 | Middle Orinoco River, Venezuela | Mogollones et al. (2010) |
| Juvenile survival | 0.44 2 | Middle Orinoco River, Venezuela | Mogollones et al. (2010) |
|  | 0.57 3 | Middle Orinoco River, Venezuela | Ramo (1982) |
| Adult survival | 0.91 2,4 | Middle Orinoco River, Venezuela | Mogollones et al. (2010) |
|  | 0.92 3 | Middle Orinoco River, Venezuela | Ramo (1982) |
| Age first reproduction | 5 - 9 yrs | Capanaparo River, Venezuela | Thorbjarnarson et al. (1993) |
| Density | 10 nests / river km | Cojedes and Manapire Rivers, Venezuela | Hernández et al. (2010) |

1predation only considered (not flooding)

2 Podocnemis expansa

3 Podocnemis vogli

4 individuals with 451-600 mm curved carapace length, i.e., approximate size of adult female *P. unifilis*

**RESULTS**

Population projections

In the absence of management or exploitation the population of *P. unifilis* increased slightly (growth rate λ = 1.02). The generation time was 16.8 years, with the population doubling after 39 years and the number of adult females doubling after 33 years (Fig. A2). The reproductive values calculated from the projection matrix indicated an exponential increase in the contribution of the different stages to future generations (5.1, 20.8, 133.3, early juvenile, late juvenile and adult respectively). Eggs/hatchlings and early stage juveniles represented the majority of the population under a stable stage distribution (90%, of which 69 and 20 percent were eggs/hatchlings and early stage juveniles respectively), whereas late juveniles represented only 5%, and adult females 6%.

Although adults represented a small proportion of the overall population, elasticity analysis revealed that survival of adult females was by far (10 times) more important in that relatively small changes in the parameter and will generate large changes in the population growth rate (elasticity 0.7 for adult female survivorship compared with 0.06 of the next highest elasticity value, Table A3). This pattern was also reflected in sensitivities, with sensitivity values highest for adult female survival, followed by late juvenile graduation (0.75, 0.57 respectively, Table A3). Similarly, proportional changes in adult survival resulted in greater changes in λ compared to all other vital rates (Figure A1).

Table A2. Vital rates (a) synthesized from the scientific literature (derived from Table A1) used to model population growth in *Podocnemis unifilis*) associated with population situations evaluated. Example of the base Lefkovitch matrix (b).

a)

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Base | Nest loss-Headstart | Nest loss-Headstart and Adult loss |
| First year survivala | 0.200 | 0.0 – 0.9 | 0.0 – 0.9 |
| Early Juvenile survival | 0.500 | 0.500 | 0.500 |
| Early Juvenile durationb | 2.000 | 2.000 | 2.000 |
| Early Pic | 0.333 | 0.333 | 0.333 |
| Early Gid | 0.167 | 0.167 | 0.167 |
| Late Juvenile survival | 0.400 | 0.400 | 0.400 |
| Late Juvenile durationb | 2.000 | 2.000 | 2.000 |
| Late Pic | 0.286 | 0.286 | 0.286 |
| Late Gid | 0.114 | 0.114 | 0.114 |
| Adult survival | 0.930 | 0.930 | 0.47, 0.70, 0.84, 0.907 |
| Annual fecunditye | 11.550 | 11.550 | 11.550 |

aEgg and hatchling

bYears

cPi = probability of a juvenile surviving and remaining in the juvenile stage.

dGi = probability of a juvenile surviving and “graduating” to the adult stage.

eClutch size X number of clutches X breeding frequency

b)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Egg | Early Juvenile | Late Juvenile | Adult |
| Egg | 0 | 0 | 0 | 11.550 |
| Early Juvenile | 0.200 | 0.333 | 0 | 0 |
| Late Juvenile | 0 | 0.167 | 0.286 | 0 |
| Adult | 0 | 0 | 0.114 | 0.930 |



Figure A1. Population growth rate (lambda λ) versus percentage change in stage-specific vital rates and fertility from the stable baseline model (λ = 1.02) for yellow-spotted river turtles

Table A3. Projection matrix model analysis. Eigenvalue analysis of stage-specific demographic parameters and vital rates resulting in a decreasing population (λ < 1) when other values are held constant for yellow-spotted river turtles (*Podocnemis unifilis*).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Vital rate | Base | Value resulting in λ < 1 (% change) | | Elasticity | Sensitivity |
| First year survivala | 0.200 | 0.151 | (24.5) | 0.064 | 0.326 |
| Early Pic | 0.333 | 0.119 | (64.3) | 0.031 | 0.095 |
| Early Gid | 0.167 | 0.126 | (24.4) | 0.064 | 0.391 |
| Late Pic | 0.286 | 0.057 | (80.1) | 0.025 | 0.089 |
| Late Gid | 0.114 | 0.086 | (24.8) | 0.064 | 0.570 |
| Adult survival | 0.930 | 0.907 | ( 2.5) | 0.687 | 0.752 |
| Annual fecunditye | 11.550 | 8.749 | (24.3) | 0.064 | 0.006 |

aEgg and hatchling

cPi = probability of a juvenile surviving and remaining in the juvenile stage.

dGi = probability of a juvenile surviving and “graduating” to the adult stage.

eClutch size X number of clutches X breeding frequency

Comparing scenarios that increased population sizes through headstarting (increasing first year survival), the population doubling time halved (reduced from 39 to 14 years) when first year survival increased from 0.2 to 0.3 (Figure A2). The number of adult females also increased as a result of headstarting, for example, when first year survival increased from 0.2 to 0.3 the adult population doubling time halved (reduced from 33 to 14 years) (Figure A2). With first year survival ≥ 0.5, the adult population was predicted to double in 8 or less years.



Figure A2. Population projections. Projected *Podocnemis unifilis* populations under different management and female harvest scenarios.

Exploitation of different stage-classes generated equally rapid population reductions, which became increasingly rapid with increasing exploitation intensity (Figure A2). If all nests were removed (zero first year survival), populations halved in 12 years and the number of adult females halved in 16 years. After 50 years (approximately three generations) only 4% (41 individuals) of adult females remained when all nests were removed (Figure 1). If first year survival was reduced to half of the base level (0.1), then populations halved after 38 years and numbers of adult females halved after 47 years (Figure A2). These losses were intensified when adult females were exploited. For example our projections estimated that half of all individuals, including half of all females were lost after only 16 years when hatchling graduation remained at the base level but 10% of females were exploited (Figure A2).

Population growth and projections were sensitive to small reductions in adult survival (Table A3), yet small losses could be compensated by headstarting, which maintained positive population growth (λ > 1) in the presence of adult exploitation (Figure A2). When adult survival was set to the level where λ < 1 (0.907, Table A3), populations were predicted to increase when headstarted first year survival was > 0.2 (Figure A2). Predictions for the number of adult females showed a similar pattern, with increases possible when headstarting increased first year survival (Figure A2). The headstarting level required to maintain population growth increased with the level of adult exploitation (Figure A2). For example, >70% first year survival (more than a threefold increase above base levels) was needed to compensate for predicted losses suffered when 25% of adults were harvested per year (Figure A2). To achieve such elevated first year survival required headstarting both eggs and hatchlings (Figure A3).



Figure A3. Headstarting scenarios. Hatchling graduation across ranges of egg and hatchling survival. Dashed horizontal lines indicate minimum graduation percentages necessary to maintain populations with base demographic parameters and 25% female harvest [e.g. 70% egg suvival and 100% hatchling survival provide minimum graduation (70%) necessary to maintain population levels at 25% female harvest].

References

Arraes D.R.d.S., Tavares-Dias M. (2014) Nesting and neonates of the yellow-spotted river turtle (Podocnemis unifilis, Podocnemididae) in the Araguari River basin, eastern Amazon, Brazil. *Acta Amazonica* **44**, 387-392.

Carr A. (1952) *Handbook of Turtles: The turtles of the United States, Canada, and Baja California Handbook of Turtles: The turtles of the United States, Canada, and Baja California*. Cornell University Press, Ithaca, New York.

Caswell H. (2001) *Matrix population models. Construction, Analysis and Interpretation*. Sinauer, Sunderland, Massachusetts.

Chinsamy A., Valenzuela N. (2008) Skeletochronology of the endangered side-neck turtle, Podocnemis expansa. *South African Journal of Science* **104**, 311-314.

Congdon J.D., Dunham A.E., Sels R.V.L. (1994) Demographics of common snapping turtles (Chelydra serpentina): implications for conservation and management of long-lived organisms. *American Zoologist* **34**, 397-408.

Congdon J.D., Dunham A.E., van Loben Sels R. (1993) Delayed sexual maturity and demographics of Blanding's Turtles (Emydoidea blandingii): Implications for conservation and management of long‐lived organisms. *Conservation Biology* **7**, 826-833.

Crouse D.T., Crowder L.B., Caswell H. (1987) A stage‐based population model for loggerhead sea turtles and implications for conservation. *Ecology* **68**, 1412-1423.

Erickson J., Baccaro F. (2016) Nest predation of the yellow-spotted Amazon River turtle (Podocnemis unifilis, Troschel, 1848) by the fire ant (Solenopsis geminata, Fabricius, 1804) in the Brazilian Amazon. *The Herpetological Journal* **26**, 183-186.

Escalona T., Fa J.E. (1998) Survival of nests of the terecay turtle (*Podocnemis unifilis*) in the Nichare-Tawadu rivers, Venezuela. *Journal of Zoology* **244**, 303-312.

Ferreira P.D., Castro P.T.A. (2010) Nesting ecology of *Podocnemis expansa* (Schweigger, 1812) and *Podocnemis unifilis* (Troschel, 1848) (Testudines, Podocnemididae) in the Javaes River, Brazil. *Brazilian Journal of Biology* **70**, 85-94.

Foote R.W. (1978) Nesting of Podocnemis unifilis (Testudines: Pelomedusidae) in the Colombian Amazon. *Herpetologica* **34**, 333-339.

Gurley R. (2017) Yellow-spotted River Turtle Care Sheet.Reptiles Magazine.

Hernández O., Espinosa-Blanco A.S., May L.C., Jiménez-Oraa M., Seijas A.E. (2010) Artificial incubation of yellow-headed sideneck turtle Podocnemis unifilis eggs to reduce losses to flooding and predation, Cojedes and Manapire Rivers, southern Venezuela. *Conservation Evidence* **7**, 100-105.

Iverson J.B. (1991) Patterns of survivorship in turtles (order Testudines). *Canadian Journal of Zoology* **69**, 385-391.

Lefkovitch L. (1965) The study of population growth in organisms grouped by stages. *Biometrics*, 1-18.

Merow C., Dahlgren J.P., Metcalf C.J.E. *et al.* (2014) Advancing population ecology with integral projection models: a practical guide. *Methods in Ecology and Evolution* **5**, 99-110.

Mogollones S.C., Rodriguez D.J., Hernandez O., Barreto G.R. (2010) A demographic study of the arrau turtle (*Podocnemis expansa*) in the Middle Orinoco River, Venezuela. *Chelonian Conservation and Biology* **9**, 79-89.

Ojasti J. (1996) Wildlife utilization in Latin America: current situation and prospects for sustainable management.Food & Agriculture Org.

Pignati M.T., Fernandes L.F., Miorando P.S., Ferreira P.D., Pezzuti J.C. (2013) Effects of the nesting environment on embryonic development, sex ratio, and hatching success in Podocnemis unifilis (Testudines: Podocnemididae) in an area of várzea floodplain on the lower Amazon River in Brazil. *Copeia* **2013**, 303-311.

Pike D.A., Pizzatto L., Pike B.A., Shine R. (2008) Estimating survival rates of uncatchable animals: The myth of high juvenile mortality in reptiles. *Ecology* **89**, 607-611.

R Development Core Team. (2017) R: A language and environment for statistical computing.R Foundation for Statistical Computing, Vienna, Austria.

Ramo C. (1982) Biología del galápago Podocnemis vogli. (Muller, 1935) en Hato el Frío, llanos de Apure. (Venezuela). *Doñana Acta Vertebrata* **9**, 1-61.

Stott I., Hodgson D., Townley S. (2016) popdemo: Demographic Modelling Using Projection Matrices.

Stubben C., Milligan B. (2007) Estimating and analyzing demographic models using the popbio package in R. *Journal of Statistical Software* **22**, 1-23.

Thorbjarnarson J.B., Perez N., Escalona T. (1993) Nesting of *Podocnemis unifilis* in the Capanaparo River, Venezuela. *Journal of Herpetology* **27**, 344-347.

Vanzolini P.E. (2003) On clutch size and hatching success of the South American turtles *Podocnemis expansa* (Schweigger, 1812) and *P-unifilis* Troschel, 1848 (Testudines, Podocnemididae). *Anais Da Academia Brasileira De Ciencias* **75**, 415-430.

Vogt R. (2008) *Tartarugas da Amazonia*. INPA, Manaus.

Zimmer-Shaffer S.A., Briggler J.T., Millspaugh J.J. (2014) Modeling the effects of commercial harvest on population growth of river turtles. *Chelonian Conservation and Biology* **13**, 227-236.

**Supplemental Material B. Population scenario mapping.**

**pan-Amazonian river basins and channel network**

To enable spatially explicit modelling of *P. unifilis* populations we combined data from several freely available sources. Amazon river subbasins (level 2) and rivers (Stahler tributary order ≥6) were obtained from Venticinque et al. (2016). We combined these with Orinoco and Atlantic subbasins and rivers obtained from the HYDRO1k database courtesy of the U.S. Geological Survey (<https://lta.cr.usgs.gov/HYDRO1K>). Both sources provide similar (highly correlated stream networks), as such, combining the datasets does not generate any systematic bias in the comparison between subbasins. We retained only larger rivers (Stahler tributary order ≥ 6) as these generally provide year round navigable access for humans (i.e. represent access during the low water nesting season) and also larger rivers have nesting areas for *P. unifilis* that are known to move out from smaller tributaries to find suitable nesting areas in larger river channels during the nesting season. Although *P. unifilis* use different waterways including small streams their reproduction and population demographics depends on the larger rivers, as the smaller rivers/streams either dry out (are not accessible to the turtles and are therefore avoided during low water (nesting) seasons or are too small to hold beach areas for nesting. As such female *P. unifilis* are thought to congregate at larger rivers during the nesting season, which is when they are most susceptible to human hunters. Our estimates are therefore estimates of suitable river areas for the reproductively mature adult female nesting population, spatially representative of the seasonal aggregation of populations that will disperse during the months with higher water levels.

**Accessibility**

There is no simple linear relationship between human population density and environmental impacts. Studies from across the world show severe effects on wildlife populations with densities as low as 0.5 people per km2, but these effects can vary with species and region. For example, a study with carnivores showed that a “critical human density” at which local population extinction was predicted to occur with a probability of 50% can be detected at less than 0.5 people per km2 , but that these effects can vary 100 fold with species and 10 fold with region (Woodroffe 2000).

The human population density in 2015 was obtained from (Lloyd et al. 2017). This data provides continuous 1km resolution population density values. We reclassified the density map to retain only cells with density values >= 3 people per km. We then calculated the distance along rivers from all non-zero cells using cost-surface analysis. With rivers providing the main access to river turtle nesting areas, we assumed that any navigable river section within 48 km of cells with a human population ≥ 3 people per km2 would be accessible by boat. This 48 km distance represents a return trip during a single day with a small “rabeta” motor (6-7 HP, 10 – 15 km per hour). This type of motor is often used for fishing and hunting trips as it is more economic (i.e. consumes less petrol) than the less efficient outboard motors. Previous studies have estimated physical human accessibility within 9 km (Peres and Lake 2003), but considering the modern day mobility of riverine communities, this value seems likely to be an underestimate. For example, a recent study showed that fishing effects radiated to 1000 km along rivers from a major urban center of 2.1 million people in the central Brazilian Amazon (Tregidgo et al. 2017).

**Protected areas.**

We obtained georeferenced polygons of protected areas from the World Database on Protected Areas (WDPA, downloaded from <https://protectedplanet.net/> on 6 December 2017). Unlike terrestrial habitats, there is no evidence to suggest any meaningful difference in the effectiveness of legal governance and / or enforcement between the different types of terrestrial protected area classes for aquatic species, including river turtles. We did not consider effects of habitat change in our models. Habitat changes generally induces negative effects on reptile species richness and beta diversity (Gardner et al. 2007). However, studies focus largely on terrestrial species and do not include semi-aquatic river turtles, making it difficult to extrapolate effects to these species. Habitat changes will have indirect effects via changes in water levels and river discharge, but *P. unifilis* has a wide distribution (Figure S2) and occurs in diverse waters and habitat types (forest, savannas, wetlands).

References

Lloyd, C.T., Sorichetta, A., Tatem, A.J., 2017. High resolution global gridded data for use in population studies. Scientific Data 4, 170001.

Peres, C.A., Lake, I.R., 2003. Extent of nontimber resource extraction in tropical forests: accessibility to game vertebrates by hunters in the Amazon basin. Conservation Biology 17, 521-535.

Tregidgo, D.J., Barlow, J., Pompeu, P.S., de Almeida Rocha, M., Parry, L., 2017. Rainforest metropolis casts 1,000-km defaunation shadow. Proceedings of the National Academy of Sciences 114, 8655-8659.

Venticinque, E., Forsberg, B., Barthem, R., Petry, P., Hess, L., Mercado, A., Cañas, C., Montoya, M., Durigan, C., Goulding, M., 2016. An explicit GIS-based river basin framework for aquatic ecosystem conservation in the Amazon. Earth System Science Data 8, 651.

Woodroffe, R., 2000. Predators and people: using human densities to interpret declines of large carnivores, In Animal Conservation forum. pp. 165-173. Cambridge University Press.

**Tables**

Table S1. Countrywide population projections. Values from projected population changes with management scenarios across nine countries.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Country | Catchment | | |  | | River length a | | | | | | |  | | | | 50 Year Population Scenarios (N / % change) | | | | | | | |
| # | PA % | Area (M km2) |  | PA % | | Total km | Accessible (km) | | Inaccessible (km) | |  | | | Currentb | | | BAUc | | Prd | | CBMe | |
|  |  | (PA / Non-PA) |  |  | | (PA / Non-PA) | PA | Non-PA | PA | Non-PA | | |  | |  | | |  | |  | |  |
| Bolivia | 2 | 25.0 | 0.76  (0.19 / 0.57) |  | 23.9 | | 18,665  (4454 / 14211) | 4,027 | 13,014 | 439 | 1,196 | | |  | | 0.19 | | | 0.04 / -75.9 | | 0.15 / -18.8 | | 0.81 / 333.9 |
| Brazil | 31 | 43.4 | 5.12  (2.22 / 2.90) |  | 41.1 | | 123,174  (50592 / 72582) | 29,271 | 63,146 | 21,283 | 9,403 | | |  | | 1.23 | | | 0.82 / -33.1 | | 1.60 / 29.9 | | 4.54 / 268.6 |
| Colombia | 8 | 16.5 | 0.70  (0.11 / 0.58) |  | 13.3 | | 18,513  (2462 / 16051) | 794 | 10,846 | 1,679 | 5,185 | | |  | | 0.19 | | | 0.18 / -0.90 | | 0.20 / 10.5 | | 0.82 / 343.9 |
| Ecuador | 3 | 26.7 | 0.13  (0.35 / 0.97) |  | 18.7 | | 3,278  (612 / 2666) | 578 | 2,541 | 31 | 123 | | |  | | 0.03 | | | 0.00 / -86.7 | | 0.02 / -39.9 | | 0.15 / 370 |
| French Guiana | 9 | 54.4 | 0.89  (0.48 / 0.40) |  | 54.7 | | 2,008  (1099 / 910) | 756 | 724 | 337 | 189 | | |  | | 0.02 | | | 0.01 / -29.7 | | 0.03 / 70.1 | | 0.06 / 182.6 |
| Guyana | 16 | 9.1 | 0.22  (0.02 / 0.19) |  | 10.4 | | 4,995  (518 / 4478) | 336 | 3,000 | 189 | 1,472 | | |  | | 0.05 | | | 0.04 / -11.1 | | 0.05 / 6.7 | | 0.22 / 342 |
| Peru | 10 | 20.9 | 0.99  (0.21 / 0.78) |  | 12.7 | | 23,764  (3030 / 20734) | 2,100 | 19,480 | 931 | 1,238 | | |  | | 0.24 | | | 0.06 / -74.9 | | 0.12 / -51.5 | | 1.21 / 407.5 |
| Suriname | 10 | 16.0 | 0.14  (0.02 / 0.12) |  | 11.0 | | 3,448  (378 / 3070) | 84 | 1,863 | 296 | 1,206 | | |  | | 0.03 | | | 0.04 / 16.2 | | 0.04 / 22.7 | | 0.15 / 333.9 |
| Venezuela | 8 | 46.6 | 0.69  (0.32/ 0.37) |  | 40.8 | | 18,112  (7389 / 10724) | 3,331 | 9,080 | 4,051 | 1,629 | | |  | | 0.18 | | | 0.15 / -16.0 | | 0.24 / 32.8 | | 0.69 / 279.2 |
| **Totals** | **53** | **36.0** | **8.86**  **(3.19 / 5.67)** |  | **32.7** | | **215,975**  **(70,533 / 145,442)** | **41,277** | **123,694** | **29,236** | **21,641** | | |  | | **2.16** | | | **1.37 / - 36.7** | | **2.46 / 14.0** | | **8.6 / 300.4** |

a All rivers (Stahler order ≥6 ) within 49 km to nearest point with at least 3 people per km2 are deemed to be accessible.

b Density of 10 females per river kilometer.

c Business as usual (BAU). Accessible populations with nest collection (hatchling graduation 0.1) and adult harvest (10%). Inaccessible at base rates (see Supplemental Material A Table A2 for population parameter values).

d Protection (Pr). Accessible populations that are in contact/within any type of protected area become “inaccessible” and demographics set to base rates. Accessible populations outside of protected areas with nest collection (hatchling graduation 0.1) and adult harvest (10%). Inaccessible at base rates (see Supplemental Material A Table A2 for population parameter values).

e Community-based management (CBM). Accessible populations inside protected as per BAU (nest collection (hatchling graduation 0.1) and adult harvest (10%)). Accessible populations that are outside of protected areas with headstarting (hatchling graduation 0.5) and adult harvest (10%). Inaccessible at base rates (see Supplemental Material A Table A2 for population parameter values).

Table S2. Catchment population projections. Projected population changes with human management and exploitation across 53 Pan-Amazonian catchments.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Catchment** | | | | | | |  | **River length** | | | | | |  | **50 Year Population Scenarios (N / % change)** | | | | | | |
| Name | | | | | PA % | Area (M km2) |  | PA % | Total km | Accessible (km) | | Inaccessible (km) | |  | Actualb | BAUc | | Prd | | CBMe | |
|  | |  | | | (PA/Non-PA) |  |  | (PA/Non-PA) | PA | Non-PA | PA | Non-PA |  |
| Amazon | |  | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Abacaxis | | | | 52.0 | 0.128  (0.067/0.062) |  | 52.5 | 3034  (1592/1442) | 805 | 751 | 787 | 687 |  | 30300 | 39311 | 29.7 | 60633 | 100.1 | 83481 | 175.5 |
|  | Amazon floodplain | | | | 31.9 | 0.380  (0.121/0.259) |  | 24.0 | 10136  (2430/7706) | 2350 | 7534 | 73 | 164 |  | 101210 | 7172 | -92.9 | 69418 | -31.4 | 450285 | 344.9 |
|  | Curuá-una | | | | 14.7 | 0.031  (0.005/0.026) |  | 0.1 | 680  (1/680) | 0 | 679 | 0 | 0 |  | 6790 | 60 | -99.1 | 60 | -99.1 | 39995 | 489.0 |
|  | Guama | | | | 1.4 | 0.073  (0.001/0.072) |  | 1.1 | 1747  (19/1728) | 20 | 1729 | 0 | 0 |  | 17490 | 154 | -99.1 | 684 | -96.1 | 101846 | 482.3 |
|  | Japurá - Caquetá | | | | 29.6 | 0.253  (0.075/0.178) |  | 25.8 | 6341  (1638/4704) | 235 | 2181 | 1397 | 2518 |  | 63310 | 104259 | 64.7 | 110483 | 74.5 | 232534 | 267.3 |
|  | Jari | | | | 85.0 | 0.134  (0.114/0.02) |  | 83.8 | 3102  (2599/503) | 1368 | 427 | 1232 | 71 |  | 30980 | 34787 | 12.3 | 71022 | 129.3 | 59901 | 93.4 |
|  | Javari | | | | 72.4 | 0.109  (0.079/0.03) |  | 61.2 | 3260  (1994/1266) | 799 | 969 | 1196 | 298 |  | 32620 | 39861 | 22.2 | 61024 | 87.1 | 96853 | 196.9 |
|  | Juruá | | | | 37.8 | 0.192  (0.073/0.119) |  | 37.0 | 4420  (1637/2783) | 1180 | 2497 | 452 | 287 |  | 44160 | 19964 | -54.8 | 51220 | 16.0 | 166826 | 277.8 |
|  | Jutai | | | | 63.6 | 0.090  (0.057/0.033) |  | 62.6 | 1855  (1161/693) | 502 | 418 | 656 | 271 |  | 18470 | 24717 | 33.8 | 38014 | 105.8 | 49302 | 166.9 |
|  | Madeira | | | | 31.5 | 1.394  (0.440/0.955) |  | 27.6 | 33952  (9354/24598) | 7318 | 22164 | 2045 | 2424 |  | 339510 | 121372 | -64.3 | 315209 | -7.2 | 1424951 | 319.7 |
|  | Madeirinha | | | | 54.4 | 0.037  (0.020/0.017) |  | 57.8 | 851  (492/359) | 462 | 358 | 29 | 0 |  | 8490 | 843 | -90.1 | 13080 | 54.1 | 21899 | 157.9 |
|  | Manacapuru | | | | 3.3 | 0.011  (0.000/0.011) |  | 1.5 | 580  (8/572) | 8 | 422 | 0 | 149 |  | 5790 | 3998 | -31.0 | 4210 | -27.3 | 28818 | 397.7 |
|  | Marañón | | | | 13.8 | 0.366  (0.051/0.315) |  | 5.3 | 8847  (465/8382) | 351 | 7888 | 121 | 484 |  | 88440 | 16806 | -81.0 | 26103 | -70.5 | 480740 | 443.6 |
|  | Nanay | | | | 58.8 | 0.017  (0.010/0.007) |  | 55.0 | 574  (316/258) | 314 | 258 | 0 | 0 |  | 5720 | 51 | -99.1 | 8368 | 46.3 | 15225 | 166.2 |
|  | Napo | | | | 27.5 | 0.101  (0.028/0.073) |  | 20.4 | 2681  (547/2134) | 513 | 2067 | 31 | 69 |  | 26800 | 2885 | -89.2 | 16474 | -38.5 | 124456 | 364.4 |
|  | Negro | | | | 59.4 | 0.717  (0.426/0.291) |  | 57.6 | 17973  (10347/7626) | 3461 | 4253 | 6896 | 3362 |  | 179720 | 273298 | 52.1 | 364972 | 103.1 | 523439 | 191.3 |
|  | Pacajá | | | | 8.0 | 0.049  (0.004/0.045) |  | 2.3 | 1507  (35/1472) | 35 | 1470 | 0 | 0 |  | 15050 | 133 | -99.1 | 1060 | -93.0 | 86591 | 475.4 |
|  | Piorini | | | | 52.4 | 0.008  (0.004/0.004) |  | 38.2 | 227  (87/141) | 0 | 139 | 87 | 1 |  | 2270 | 2351 | 3.6 | 2351 | 3.6 | 10526 | 363.7 |
|  | Purus | | | | 53.1 | 0.376  (0.200/0.176) |  | 50.4 | 9247  (4659/4587) | 1675 | 2659 | 3007 | 1904 |  | 92450 | 130898 | 41.6 | 175265 | 89.6 | 287287 | 210.7 |
|  | Putumayo | | | | 20.4 | 0.118  (0.024/0.094) |  | 12.9 | 2713  (350/2363) | 348 | 2286 | 0 | 73 |  | 27070 | 2173 | -92.0 | 11390 | -57.9 | 136624 | 404.7 |
|  | Tapajós | | | | 36.3 | 0.508  (0.185/0.324) |  | 35.0 | 12231  (4282/7948) | 3191 | 7252 | 1083 | 713 |  | 122390 | 48653 | -60.2 | 133175 | 8.8 | 475180 | 288.3 |
|  | Tefe | | | | 12.4 | 0.060  (0.007/0.053) |  | 2.2 | 1219  (26/1192) | 25 | 928 | 0 | 263 |  | 12160 | 7074 | -41.8 | 7736 | -36.4 | 61654 | 407.0 |
|  | Tocantins | | | | 15.2 | 0.801  (0.122/0.679) |  | 17.3 | 18409  (3193/15216) | 3114 | 15081 | 71 | 139 |  | 184050 | 7188 | -96.1 | 89671 | -51.3 | 894179 | 385.8 |
|  | Trombetas | | | | 88.4 | 0.150  (0.133/0.017) |  | 84.6 | 3695  (3125/570) | 911 | 530 | 2195 | 55 |  | 36910 | 59923 | 62.3 | 84054 | 127.7 | 91095 | 146.8 |
|  | Uatumá | | | | 15.0 | 0.073  (0.039/0.035) |  | 40.4 | 1483  (598/885) | 433 | 848 | 157 | 44 |  | 14820 | 4458 | -94.4 | 14259 | -81.9 | 438573 | 455.6 |
|  | Ucayali | | | | 52.9 | 0.366  (0.055/0.311) |  | 5.1 | 7899  (406/7493) | 370 | 7381 | 37 | 105 |  | 78930 | 5455 | -63.2 | 16924 | 14.2 | 55330 | 273.3 |
|  | Xingu | | | | 56.7 | 0.520  (0.295/0.225) |  | 58.4 | 12318  (7191/5127) | 4522 | 4479 | 2660 | 654 |  | 123150 | 88868 | -27.8 | 208645 | 69.4 | 352301 | 186.1 |
| **Basin total** | | | |  | **37.3** | **7.064**  **(2.632/4.432)** |  | **34.2** | **170,981 (58555/112426)** | **34,310** | **97,648** | **24,212** | **14,735** |  | **1,709,050** | **1,046,712** |  | **1,955,505** |  | **6,789,891** |  |
| Coastal North | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Berbice | | | | 0 | 0.017  (0.00/0.016) |  | 0 | 419  (0/419) | 0 | 334 | 0 | 85 |  | 4190 | 2288 | -45.4 | 2288 | -45.4 | 21933 | 423.5 |
|  | Coastal basins North | | | | 73 | 0.112  (0.080/0.03) |  | 63.8 | 2297  (1465/832) | 997 | 706 | 463 | 128 |  | 22940 | 15857 | -30.9 | 42265 | 84.2 | 57380 | 150.1 |
|  | Coppename | | | | 46.3 | 0.022  (0.010/0.012) |  | 49.9 | 542  (270/271) | 10 | 234 | 263 | 33 |  | 5400 | 7888 | 46.1 | 8153 | 51.0 | 21651 | 300.9 |
|  | Courantyne | | | | 8.5 | 0.066  (0.006/0.06) |  | 1.9 | 1777  (34/1743) | 0 | 197 | 33 | 1548 |  | 17780 | 42034 | 136.4 | 42034 | 136.4 | 53621 | 201.6 |
|  | Demerara | | | | 0 | 0.008  (0.000/0.008) |  | 0 | 204  (0/204) | 0 | 204 | 0 | 0 |  | 2040 | 18 | -99.1 | 18 | -99.1 | 12016 | 489.0 |
|  | Essequibo | | | | 26.3 | 0.159  (0.042/0.117) |  | 25.3 | 3681  (932/2749) | 743 | 2015 | 197 | 721 |  | 36760 | 24640 | -33.0 | 44321 | 20.6 | 143153 | 289.4 |
|  | Guy1 | | | | 7.4 | 0.010  (0.001/0.009) |  | 7.5 | 222  (17/205) | 17 | 206 | 0 | 0 |  | 2230 | 20 | -99.1 | 470 | -78.9 | 12136 | 444.2 |
|  | Guy10 | | | | 0 | 0.001  (0/0.001) |  | 0 | 0  (0/0) | 0 | 0 | 0 | 0 |  | 0 |  |  |  |  |  |  |
|  | Guy11 | | | | 12.4 | 0.003  (0/0.003) |  | 54.1 | 6  (3/3) | 3 | 3 | 0 | 0 |  | 60 | 1 | -99.1 | 80 | 33.3 | 177 | 195.0 |
|  | Guy12 | | | | 1 | 0.002  (0/0.002) |  | 0 | 24  (0/24) | 0 | 24 | 0 | 0 |  | 240 | 2 | -99.1 | 2 | -99.1 | 1414 | 489.0 |
|  | Guy13 | | | | 5.6 | 0.012  (0.001/0.011) |  | 1.4 | 195  (3/192) | 3 | 132 | 0 | 58 |  | 1930 | 1553 | -19.5 | 1633 | -15.4 | 9317 | 382.7 |
|  | Guy2 | | | | 0 | 0.004  (0/0.004) |  | 0 | 42  (0/42) | 0 | 42 | 0 | 0 |  | 420 | 4 | -99.1 | 4 | -99.1 | 2474 | 489.0 |
|  | Guy3 | | | | 44.2 | 0.003  (0.001/0.001) |  | 0 | 8  (0/8) | 0 | 8 | 0 | 0 |  | 80 | 1 | -99.1 | 1 | -99.1 | 471 | 489.0 |
|  | Guy4 | | | | 31.9 | 0.012  (0.004/0.008) |  | 19.7 | 263  (52/211) | 51 | 182 | 3 | 27 |  | 2630 | 818 | -68.9 | 2169 | -17.5 | 11522 | 338.1 |
|  | Guy5 | | | | 12.4 | 0.006  (0.001/0.005) |  | 17.1 | 71  (12/59) | 13 | 59 | 0 | 0 |  | 720 | 6 | -99.1 | 351 | -51.3 | 3476 | 382.8 |
|  | Guy6 | | | | 29.8 | 0.007  (0.002/0.005) |  | 7.7 | 181  (14/167) | 7 | 157 | 7 | 10 |  | 1810 | 466 | -74.2 | 652 | -64.0 | 9700 | 435.9 |
|  | Guy7 | | | | 80.4 | 0.004  (0.004/0.001) |  | 91.4 | 113  (104/10) | 102 | 8 | 3 | 0 |  | 1130 | 89 | -92.1 | 2791 | 147.0 | 560 | -50.4 |
|  | Guy9 | | | | 0 | 0.002  (0/0.002) |  | 0 | 26  (0/26) | 0 | 27 | 0 | 0 |  | 270 | 2 | -99.1 | 2 | -99.1 | 1590 | 489.0 |
|  | Maroni | | | | 31.2 | 0.068  (0.021/0.047) |  | 33.0 | 1623  (536/1087) | 311 | 839 | 213 | 258 |  | 16210 | 12619 | -22.2 | 20857 | 28.7 | 61965 | 282.3 |
|  | Mururuma | | | | 0.8 | 0.008  (0/0.008) |  | 0 | 226  (0/226) | 0 | 226 | 0 | 0 |  | 2260 | 20 | -99.1 | 20 | -99.1 | 13312 | 489.0 |
|  | Saramacca | | | | 28.3 | 0.010  (0.003/0.007) |  | 3.7 | 291  (11/281) | 12 | 280 | 0 | 0 |  | 2920 | 26 | -99.1 | 344 | -88.2 | 16494 | 464.9 |
|  | Suriname | | | | 6.5 | 0.015  (0.001/0.014) |  | 1.4 | 497  (7/490) | 6 | 468 | 0 | 24 |  | 4980 | 680 | -86.4 | 839 | -83.2 | 28205 | 466.4 |
| **Basin total** | | |  | | **32.1** | **0.547**  **(0.176/0.372)** |  | **27.2** | **12708**  **(3459/9249)** | **2,275** | **6,351** | **1,182** | **2,892** |  | **127,000** | **109,033** |  | **169,292** |  | **482,567** |  |
| Coastal South | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Coastal basins South | | | | **26.0** | **0.269**  **(0.070/0.199)** |  | **23.4** | **5714**  **(1337/4377)** | **1,339** | **4,372** | **0** | **0** |  | **57,110** | **504** | -99.1 | **35,971** | -37.0 | **257,644** | 351.1 |
| Orinoco | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Orinoco floodplain | | | | 23.0 | 0.012  (0.003/0.009) |  | 11.6 | 1103  (128/975) | 124 | 926 | 16 | 26 |  | 10920 | 1209 | -88.9 | 4493 | -58.9 | 55672 | 409.8 |
|  | Orinoco Guayana | | | | 46.9 | 0.532  (0.249/0.283) |  | 46.6 | 12497  (5817/6680) | 2231 | 3805 | 3587 | 2866 |  | 124890 | 172028 | 37.7 | 231122 | 85.1 | 395820 | 216.9 |
|  | Orinoco Llanos | | | | 12.2 | 0.412  (0.050/0.362) |  | 9.6 | 12955  (1238/11717) | 999 | 10592 | 239 | 1122 |  | 129520 | 37194 | -71.3 | 63655 | -50.9 | 660163 | 409.7 |
| **Basin total** | | |  | | **31.6** | **0.957**  **(0.303/0.654)** |  | **27.0** | **26555**  **(7183/19372)** | **3354** | **15323** | **3842** | **4014** |  | **265,330** | **210,431** |  | **299,271** |  | **1,111,655** |  |
| **Total** | | | | | **36.0** | 8.86  (3.19 / 5.67) |  |  | **215,975**  (70533/145442) | **41,278** | **123,694** | **29,236** | **21,641** |  | **2,159,750** | **1,366,680** |  | **2,460,039** |  | **8,641,757** |  |

a All rivers (Stahler order ≥6 ) within 49 km to nearest point with at least 3 people per km2 are deemed to be accessible.

b Density of 10 females per river kilometer.

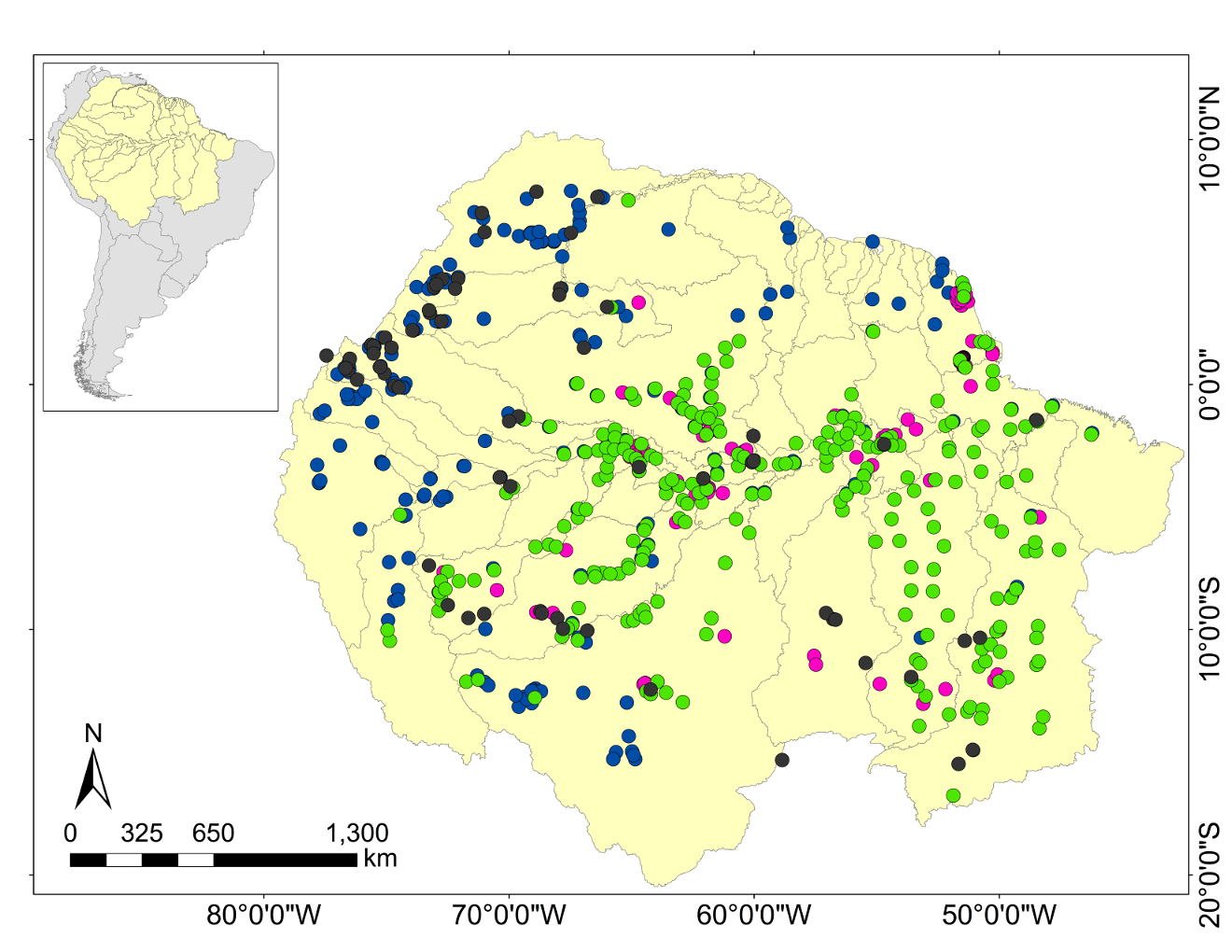
c Business as usual (BAU). Accessible populations with nest collection (hatchling graduation 0.1) and adult harvest (10%). Inaccessible at base rates (see Supplemental Material A Table A2 for population parameter values).

d Protection (Pr). Accessible populations that are in contact/within any type of protected area become “inaccessible” and demographics set to base rates. Accessible populations outside of protected areas with nest collection (hatchling graduation 0.1) and adult harvest (10%). Inaccessible at base rates (see Supplemental Material A Table A2 for population parameter values).

e Community-based management (CBM). Accessible populations inside protected as per BAU (nest collection (hatchling graduation 0.1) and adult harvest (10%)). Accessible populations that are outside of protected areas with headstarting (hatchling graduation 0.5) and adult harvest (10%). Inaccessible at base rates (see Supplemental Material A Table A2 for population parameter values).

**Figures**

Figure S1. Data points from four different sources used for mapping the presence of *Podocnemis unifilis* in 53 Pan-Amazonian river catchments. Black, green, pink and blue circles correspond to Species Link, ICMBio/RAN, Salinero & Michalski 2016, and GBIF sources, respectively.



References

GBIF (Global Biodiversity Information Facility). (2018) http://www.gbif.org/. (visited 7 December 2017).

Salinero, M.C. & Michalski, F. (2016) Implications of scientific collaboration networks on studies of aquatic vertebrates in the Brazilian Amazon. *PLoS One*, **11**, e0158413.

Species Link. (2018) http://www.splink.org.br. (visited 19 February 2018).

RAN/ICMBio (Centro Nacional de Pesquisa e Conservação de Répteis e Anfíbios do Instituto Chico Mendes de Conservação da Biodiversidade. (2016). www.ibama.gov.br/sophia/cnia/livros/QueloniosAmazonicos.pdf. (visited 17 February 2018).

Figure S2. Population outcome conditional inference tree.

Figure S2 Conditional inference tree for population change. The tree was used to represent decision points in the response of population change, comparing the relative change in relation to scenario coverage (“cover”) across rivers in 53 catchments, according to hunting level (“hunt”, in 5 classes:“no hunt”, “2.5%”, “10%”, “25%”, “50%”) and hatchling graduation ( “hatch”, ranging from 0 to 0.9). Terminal nodes show a boxplot with median values (bold horizontal bar), 1st and 3rd quartiles (hinges), and approximate 95% confidence intervals (notches) of the group. All nodes p< 0.001.

