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Title:

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

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Abstract

Sustainable use as a mechanism for the conservation and recovery of exploited wildlife populations remains intensely debated, including for freshwater turtles, a diverse and imperilled group of aquatic reptiles that are an important food source for many residents of tropical regions. Here we evaluated the geographical extent of recovery options for a heavily exploited tropical freshwater turtle fauna across 8.86 M km^2 of South American river catchments under Business-as-Usual (BAU), Protection (Pr) and Community-Based-Management (CBM) scenarios. For the widespread indicator species, *Podocnemis unifilis,* demographic analysis showed that populations subject moderate levels of female harvest (≤10%) can recover over broad areas if concurrent headstarting of hatchlings is practiced more widely. With regional strengthening of the protected area network unlikely, CBM developed with harvest frameworks derived from demographic rates appropriate to tropical species could catalyse a rapid continental scale recovery of Amazonian freshwater turtles within a few decades.

Tweetable highlight: Community-based management could ensure the rapid continental scale recovery of conservation dependent freshwater turtles.

Highlights

- **We evaluated management scenarios for the future continental-scale recovery of a conservation dependent freshwater turtle**
  In 9 countries and 53 catchments along a cumulative river length that would stretch 5 times around the globe.
- **One third (70,533 km) of river lengths are within protected areas, two-thirds of which (1.97 M km^2) permit human use.**
  Protected area coverage of Amazonian rivers met the Aichi 2020 target (17%) across 7.1 million km^2 (79.8% of 8.86 M km^2), reaching 50% across 2.27 M km^2 (25.5% of 8.86 M km^2) among 13 of 53 river catchments.
- **Although 32.7% of rivers are protected, we estimate that most (76%, 164,971 km) of these rivers are accessible to turtle harvesters with 57.2% (123,694 km) both accessible and unprotected.**
- **Widespread human access to rivers indicates that freshwater turtle populations are likely to decline rapidly across much of their range.**
  Severe (≥50%) and rapid (<50 years) future losses were projected across 60% of the pan-Amazonian range (5.3 M km^2); in the absence of effective protection and

management a widespread indicator species, *Podocnemis unifilis,* faces imminent extirpation from Bolivia, Ecuador, and Peru.

- **Protected areas alone are clearly insufficient to ensure the future range-scale viability of the species.**
- **If adult harvest is controlled then community-based-management can catalyse a rapid continental scale recovery for the species.**

If community-based management is implemented, we predict fourfold continental scale population increases within 50 years across 8.86 M km^2.

- **Species demography and management experience suggest that this and related freshwater turtles have potential for substantial continental scale conservation gains if community-based-management can be supported over broad areas.**

1 INTRODUCTION

The conservation, recovery and sustainable use of natural resources are global priorities if we are to avoid the calamitous biodiversity losses predicted for the Anthropocene. Impacts are so widespread and rapid that most Red List vertebrate species (93%) have undergone deterioration in IUCN status, with the few successes (improvements in IUCN status) a result of direct conservation interventions (Hoffmann *et al.* 2010). Tropical regions pose a particular challenge: most biological diversity occurs in the tropics, yet rapid economic development in most tropical countries is supported by only rudimentary frameworks for wildlife protection, which are often ineffectively enforced. Particularly lacking for tropical regions is empirical guidance to inform the development of effective polices and management guidelines for the recovery and sustainable use of wild species.

The Amazon basin, the world's greatest locus of continental biodiversity, encapsulates 21st century conservation challenges. Centuries of exploitation combined with dramatic intensification of overharvesting through the 20th century (Antunes *et al.* 2016) have generated a widespread "fishing-down the food chain" process across Amazonian waterways (Antunes *et al.* 2016; Castello *et al.* 2013). Among aquatic wildlife that have been subject to rampant overexploitation are the once abundant freshwater turtles (*Podocnemis* spp.), now endangered with surviving populations indicating dramatic declines in body size (Castello *et al.* 2013; Ojasti 1996; Smith 1979; Vogt 2008). Tropical freshwater turtles have been exploited for centuries leading to widespread population declines across the Amazon through the 20th century (Castello *et al.* 2013; Smith 1979). These turtles are also a flagship reflecting the success or failure of broader efforts to protect aquatic ecosystems (Abell *et al.* 2007; Abell *et al.* 2017; Castello *et al.* 2013).

Much of our understanding of freshwater turtle population management comes from demographic analyses of temperate species, which are characterized by late onset of sexual maturity and limited capacity to deal with additive sources of adult mortality, leading to the oft-made claim that "sustainable harvest" in turtles is an oxymoron (Congdon *et al.* 1994). There is good reason to question the applicability of inference derived from temperate zone species to inform harvest management guidelines for tropical turtles (Canessa *et al.* 2016; Spencer *et al.* 2017), given the relatively extended breeding seasons, higher somatic growth rates and earlier age at first reproduction of tropical species (Moll and Moll 2004; Spencer *et al.* 2017). Reptiles with relatively fast growth rates, young age at onset of maturity and high fecundity can persist under conditions of relatively low adult survivorship (Shine and Harlow 1999). The success of conservation approaches to achieve species recovery depends on a combination of adaptive management, measureable objectives and realistic timelines (i.e., SMART criteria: *citation*) for which demographic analysis and population models are a critical tool. Such models enable understanding the dynamics of harvested populations (Morris and Doak 2002) providing a scientific foundation to inform all SMART components.

Myriad actions have been implemented to conserve tropical freshwater turtles. Headstarting, (the rearing of eggs collected from the wild with subsequent release of juveniles back to the wild), has been applied to Amazonian freshwater turtle conservation for over 40 years e.g. *Podocnemis expansa* since the early 1970s in Brazil. Yet population projections developed for freshwater turtles based on data from temperate zones suggest that headstarting cannot compensate for even small reductions (e.g. 10%) in adult survivorship, which can generate rapid population declines (Heppell *et al.* 1996). However, the utility of these diagnoses for tropical species is unclear based on pronounced differences in metabolic and demographic rates of these ectothermic species at low versus high latitudes.

Here we present a spatially explicit assessment of management scenarios for the recovery of a heavily exploited Amazonian freshwater turtle across 53 river catchments covering 8.86 million km^2. We integrate demographic data appropriate to tropical freshwater turtles in population projection models. We show that local community-based management (CBM) in which headstarting of juveniles linked to and incentivized by moderate harvest of adults can catalyse a rapid and widespread continental scale recovery trajectory for an otherwise imperilled species.

2 METHODS

2.1 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) “Lefkovitch” matrix population projection model (Supplemental Material A: Demographic model development). Our stage-structured matrix population model was based on annual increments (Caswell 2001; Heppell 1998). Matrix population model are adequate for our broad-scale analysis as both turtle life stages and their associated threats are readily discretized (Figure 1; (Heppell 1998; Smith 1979; Spencer *et al.* 2017)).

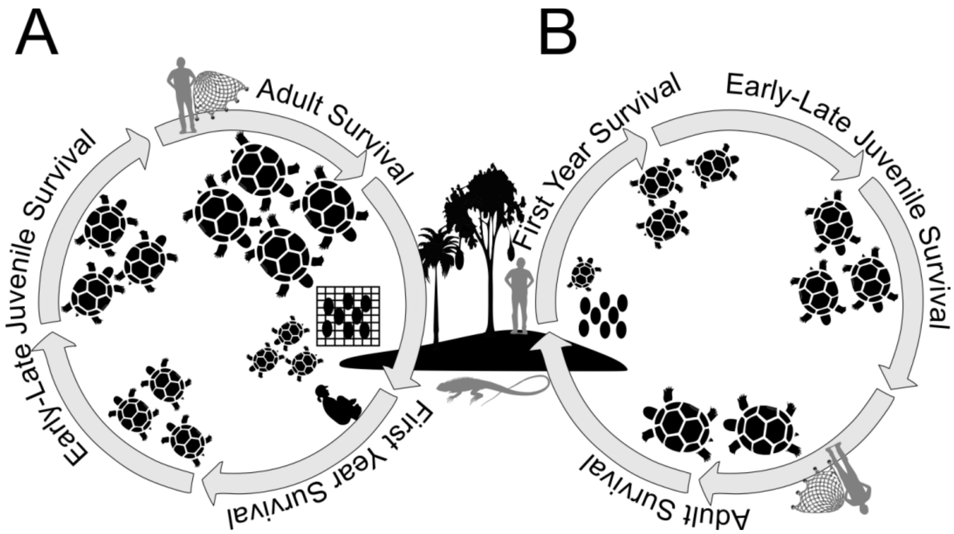

Figure 1. Life-cycle and associated threats in Amazonian freshwater turtles. Stage specific threats (human hunting, human nest harvest and natural nest predation, e.g. by teiid lizards) are represented by grey images close to the directly affected stage. The two cycles represent the differences between (A) Community-Based Management (CBM) and (B) Business-as-Usual (BAU) scenarios.

2.2 Future population changes

Estimating total population size is at best difficult and this challenge is recognized in international evaluations where populations are assessed based on percentage changes over time (IUCN Standards and Petitions Subcommittee 2017). Here we examine realistic exploitation scenarios to establish plausible future pan-Amazonian population changes. We consider projections of management options (Protection and Community-Based Management) that are widely recognized to be priorities for conservation action (Harju *et al.* 2017; Moll and Moll 2004; Spencer *et al.* 2017). We conducted analysis at the level of catchments (Supplemental Material B: Population scenario mapping) across 8.85 million km^2 as these are legally, politically, culturally and biologically relevant management units (Abell *et al.* 2007; Abell *et al.* 2017; Spencer *et al.* 2017).

Modelling was developed along a four-stage process flow:

1. We identified all catchments where *P. unifilis* has been recorded (Figure S1).

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2. To estimate a representative value of the suitable habitat we obtained the total length of all larger rivers (hereafter rivers) per catchment (Supplemental Material B: Population scenario mapping).
3. To enable spatially explicit modelling of population management and exploitation impacts, all rivers were classified as accessible or inaccessible to humans (Supplemental Material B: Population scenario mapping). Protected areas (including all categories from the World Database on Protected Areas) were also included within the classification, providing four river classes (accessible: protected and unprotected; and inaccessible: protected and unprotected).
4. We established three representative management and exploitation scenarios within which we applied spatially explicit population modelling (Table 1): Business-as-Usual (BAU), Protection (Pr) and Community-Based Management (CBM). Scenarios forecast populations within each catchment under different possible management policies

Under the BAU scenario different demographic parameters were used to project populations on accessible and inaccessible river sections, whereby accessible populations were modelled with nest collection (hatchling graduation 0.1) and 10% adult harvest and inaccessible at base rates (see Supplemental Material A Table A2). BAU reflects the persistent "paper parks" paradigm; i.e., protected areas are generally large, but underfunded and understaffed, lacking enforcement, and relying more on relative remoteness than active management to conserve biodiversity. The Protection scenario modelled the effect of effective protected areas (independent of category). Accessible rivers that intersected protected areas became "inaccessible" and population demographics set to base rate (see Supplemental Material A, Table A2). Accessible rivers outside protected areas were modelled as per Business-as-Usual. The CBM scenario modelled population management along accessible river sections outside protected areas with headstarting (hatchling graduation 0.5) and 10% adult harvest. Under the CBM scenario, accessible rivers within protected areas and inaccessible rivers were modelled as per Business-as-Usual.

2.3 Data analysis

To evaluate the likely outcomes associated with different scenarios we used decision trees (Hothorn and Zeileis 2015) in the R environment for statistical computing (R Development Core Team 2017). Decision trees were chosen as they provide a visual and analytical decision support tool enabling us to identify points of change and analyse the management alternatives that were likely to generate population increases or declines. All R codes and functions used to generate models and run analyses are available via https://github.com/darrennorris/cmartr .

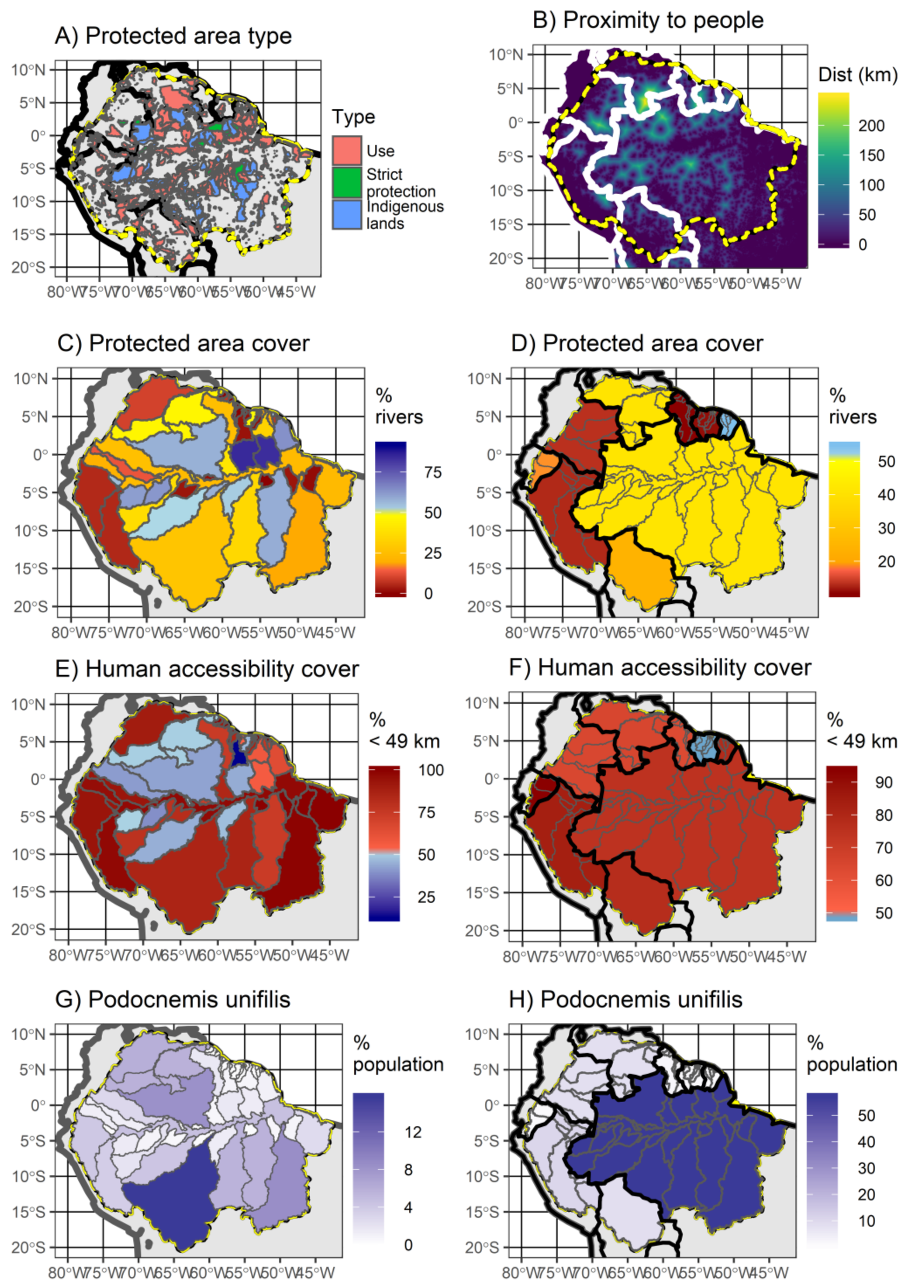

Figure 2. Basin- and country-wide patterns. Pan-Amazonian distribution of protected areas, human accessibility and yellow spotted freshwater turtle (*Podocnemis unifilis*) populations. (A) Protected area types classified from the World Database of Protected Areas (downloaded from https://www.protectedplanet.net/). Indigenous lands ("Indigenous Area", "Indigenous Reserve" and/or "Indigenous Territory"), Strictly Protected (categories Ia and Ib) and those with some form of use (categories II to VI). Solid black lines show national boundaries and black-and-yellow dashed line indicate the area covered by catchments within the species range. Percentage PA coverage of rivers in each catchment (C) and country (D). Shades of red below 17%, shades of orange between 17% and 50%

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(Aichi target) and shades of blue above 50% ("half-world" target). Percentage of waterways that are accessible (<49 km) by river from locations with a human density ⩾3 persons • km^{-2} within each catchment (E) and country (F). Percentage of the overall range wide freshwater turtle population within each catchment (G) and country (H). See Tables S1 and S2 for values per country and catchment.

3 RESULTS

3.1 Pan-Amazonian populations and protection

With Brazil containing by far the largest proportion of rivers in lowland Amazonia, this nation alone is likely to maintain 57% of the current population (Figure 2, Table S1), with 37% distributed evenly (8-10% per country) across Bolivia, Colombia, Peru and Venezuela. The remaining 6% of the current population is distributed (1-2% per country) across Ecuador in the west and French Guiana, Guyana and Suriname in the north-east. Protected area coverage was not uniform across countries or catchments (Figure 2). French Guiana was the only territory to achieve 50% protected area coverage of both terrestrial areas and river lengths (Table 1). With a strong overall protected area coverage — of 43.4% and 41.1% for terrestrial areas and rivers, respectively — the Brazilian protected area network resulted in the overall protected area coverage remaining relatively high, even when neighbouring nations achieved levels well below 17% (Figure 2, Table 1).

Protected areas, including indigenous lands currently cover approximately 36% (3.19 M km^2) of the 53 catchments (8.86 M km^2) included in our analysis. This terrestrial coverage was also reflected in the coverage of larger rivers that overlapped protected area polygons. Overall 33% (70,533 / 215,975 km) of river length was covered by protected areas (Table 1, Table S1). Yet, we estimate that 76% of rivers are accessible (Table 1, Table S1, Table S2), representing approximately 164,971 km of the overall 215,975 km river length. With protected areas covering 25% of accessible rivers (41,277 of 164,971 km), this leaves 57.2% (123,694 km) of river courses that are both accessible and formally unprotected (Table S1, Table S2).

Table 1. Countrywide population projections. Projected yellow spotted freshwater turtle (*Podocnemis unifilis*) population changes under different exploitation scenarios across nine Amazonian countries.

Country	River			Population status[b]			
	Length	PA	Acc	Current	BAU[c]	Pr[c]	CBM[c]

	(K km)	(%)	(%)				
Bolivia	18.7	23.9	91.3	VU	-EN	-VU	+VU
Brazil	123.2	41.1	75.0	NT	-VU	+NT	+NT
Colombia	18.5	13.3	62.9	EN	-EN	+EN	+EN
Ecuador	3.3	18.7	95.1	VU	-CR	-VU	+VU
French Guiana	2.0	54.7	73.7	VU	-VU	+VU	+VU
Guyana	5.0	10.4	66.8	VU	-VU	+VU	+VU
Peru	23.8	12.7	90.8	VU	-EN	-EN	+VU
Suriname	3.4	11.0	56.5	VU	+VU	+VU	+VU
Venezuela	18.1	40.8	68.5	VU	-VU	+VU	+VU
Overall	**216.0**	**32.7**	**76.4**	**VU (A1acd)**	**-VU**	**+VU**	**+VU**

[a] Summaries of rivers (Stahler tributary order ≥6) within each country. Cumulative river length per country in thousands of km; protected area coverage (PA %) is the percentage of river length overlapping protected areas of any classification from the World Database of Protected Areas (downloaded from https://www.protectedplanet.net/). Accessibility (Acc %), is the percentage of river courses within 49 km of any given point with at least 3 people per km^2.

[b] Current and projected threat status. Current status is taken from existing national and international (IUCN) Red List evaluations. The projected status changes are shown for three scenarios, with the classification following the IUCN population size reduction criteria A3bd (projected % reduction over three generations). The current status is retained when increases are projected. Cells are green when projected changes are above the minimum IUCN Red List criteria (30% reduction).

[c] Projected population scenarios: Business-as-Usual (BAU), Protection (Pr) and Community-Based Management (CBM). See Supplemental Material A Table A2 for population parameter values for each scenario and Table S1 for population scenario values (N and % change).

3.2 How much protected and/or managed habitat is enough?

Exploitation (hunting) of adult females generated population reductions, which became increasingly drastic with increasing extent of harvest across river catchments (Figure 3). If all nests were removed (zero first-year survival), populations declined when over 55% of all rivers were affected. These losses were intensified when adult females were exploited. For example, our projections estimated that enhancing hatchling graduation above the base rate (i.e. to 0.3 or

more) would be necessary to enable population increases when 10% of adult females were depleted across more than 55% of rivers (Figure 3, Supplemental Material A Figure A2). Indeed, increasing hatchling graduation to above 0.6 would also enable populations to remain stable when up to 25% of females were extracted across more than 55% of rivers (Figure 3).
Population declines occurred only when scenario coverage was above 55% (Supplemental Material A Figure A2). Population declines occurred in some cases with 2.5% or 10% hunting when hatchling graduation was≤0.3, but above this graduation threshold populations increased even with 2.5% or 10% hunting at 95% coverage (Supplemental Material A Figure A2). In contrast, population declines were predicted with >10% hunting across the range of graduation values (Figure 3, Supplemental Material A: Figure A2). For example, at 25% hunting, a hatchling graduation of 0.6 or more was required to ensure populations continued to increase across the scenario coverage values (Figure 3).

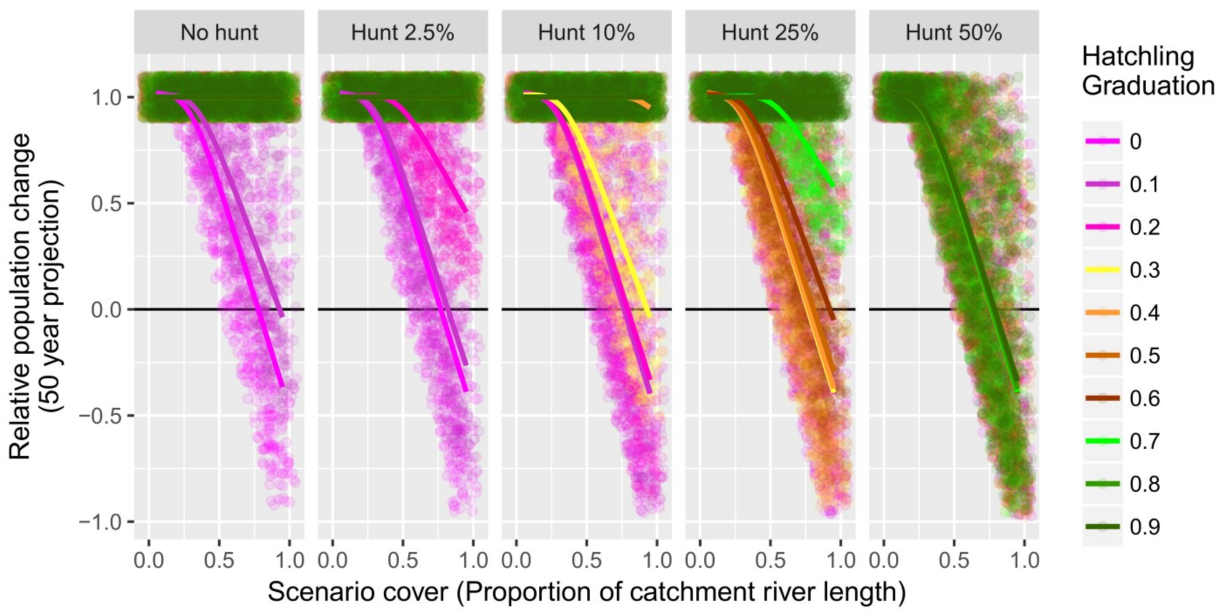

Figure 3. Extent of impact of exploitation scenarios on future population changes of yellow spotted freshwater turtles (*Podocnemis unifilis*). Projected population changes resulting from the extent of different exploitation scenarios within 53 pan-Amazonian river catchments. Positive and negative y-axis values indicate population increases and declines, respectively, and 0.5 and -0.5 represents population doubling or halving time, respectively. Solid horizontal line at 0.0 shows a stable population.

Comparing scenarios that increased population sizes through enhancing hatchling graduation above the base rate of 0.2, the population doubling time halved when first-year graduation increased from 0.2 to 0.3 (Figure 4, Supplemental Material A Figure A2). Indeed, with first-year survival ≥ 0.5, the adult population was predicted to double in eight or fewer years (Supplemental Material A Figure A2). Conversely, if all nests were removed, populations will halve in less than 12 years and if first-year graduation was reduced to half the base level (0.1), then populations would halve after 38 years (Figure 4). Our projections estimated that most individuals, including half of all females were lost after only 16 years if hatchling graduation remained at the base level but 10% of females were exploited (Figure 3, Supplemental Material A Figure A2). If hatchling graduation levels could be enhanced to 0.7 or more, then populations could continue to increase even with a 25% harvest of adult females (Figure 4). However, with 50% adult harvest we estimate that populations will decline and that increasing hatchling graduation will only delay population collapse (halving) to 24 years (Figure 4, Supplemental Material A Figure A2).

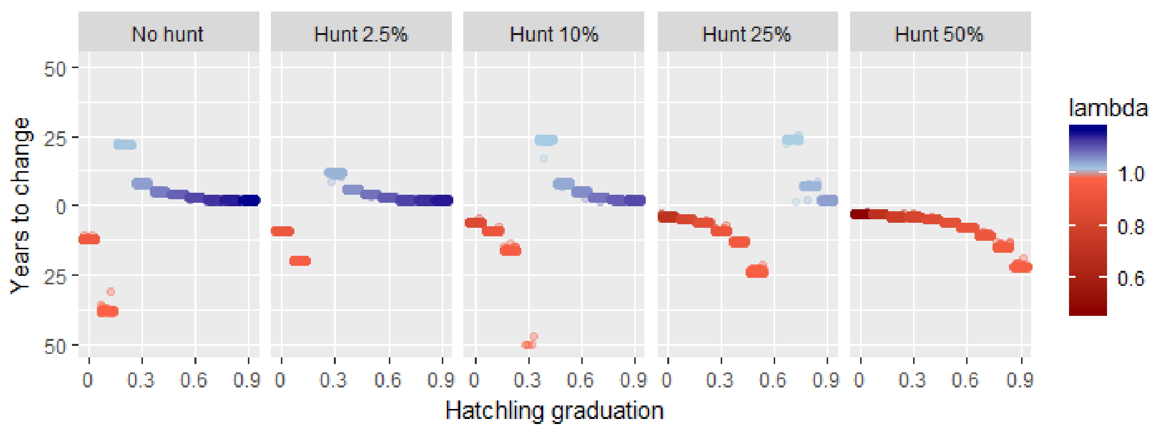

Figure 4. Time to impact of exploitation scenarios. Years to effect substantial (50%) population changes as a result of different exploitation scenarios within 53 pan-Amazonian river catchments. The time (in years) to either 50% population increases or 50% population declines are shown above zero (blue circles) or below zero (red circles), respectively.

3.3 Pan-Amazonian population projections under different exploitation scenarios

Our BAU projections showed an overall 36% reduction in the number of adult females over 50 years (Table 1, Table S1). Reductions in the number of adult females were projected in most catchments (Figure 5, Table S2), representing losses across 6.27 million km^2 or 70.8% of the total area. Severe (≥50%) losses were projected across 60% of the area (Figure 5, Table S2).

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Both the Protection and Community-Based Management scenarios reduced projected BAU losses. Although many catchments continued to experience losses under the Protection scenario, CBM enabled increases across all catchments (Figure 5, Table S2).

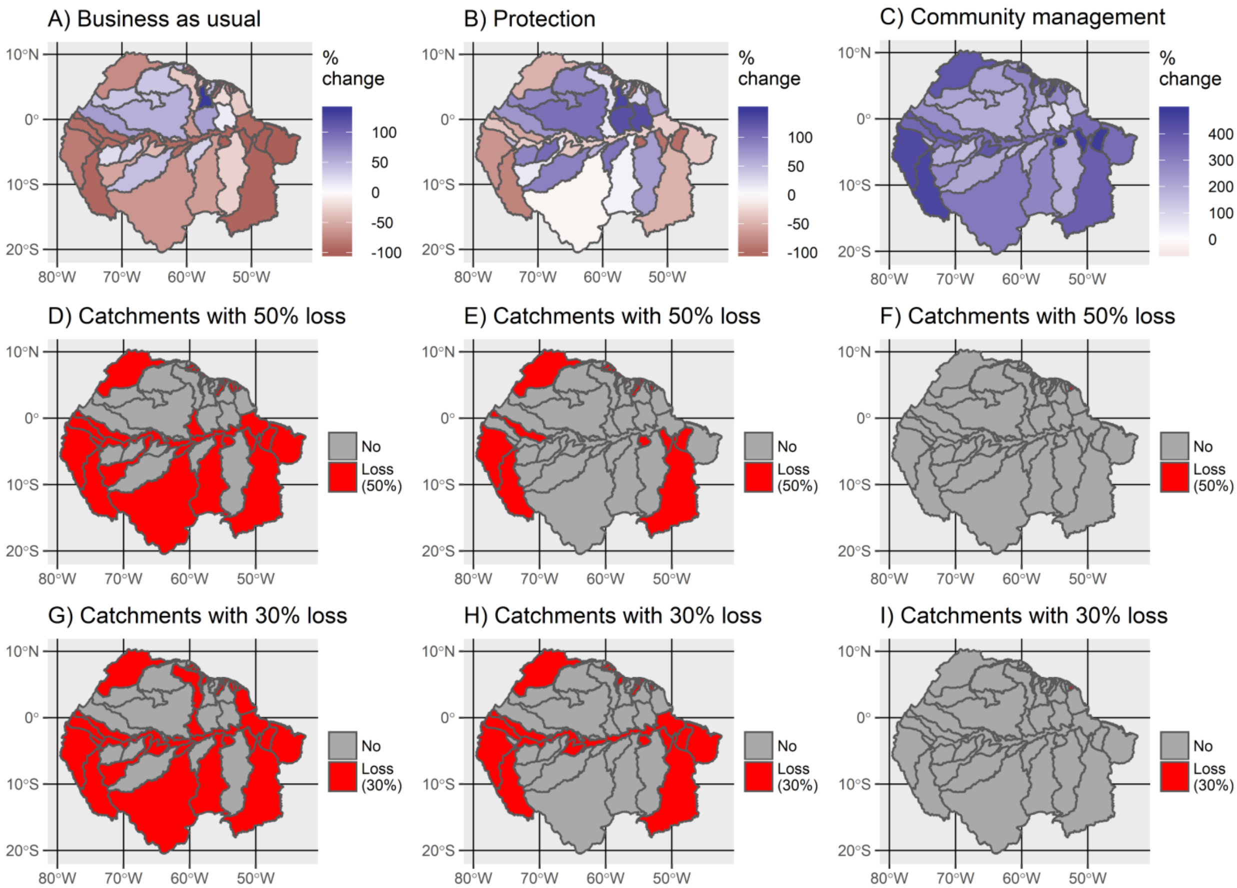

Figure 5. Pan-Amazonian projections of population changes. Projected *Podocnemis unifilis* population changes across 53 catchments. Columns represent results from three exploitation scenarios, from left to right: Business-as-Usual, Protection and Community-Based Management. Rows show percentage change in the number of adult females under different management scenarios (A –C) and river catchments projected to experience either 50% (D-F) or 30% (G-I) losses of adult females.

4 DISCUSSION

Assessments of management scenarios for the recovery of heavily exploited freshwater vertebrates are crucial to ensure meaningful long-term conservation policies over large spatial and temporal scales. Here we modelled the exploitation and management scenarios for Amazonian freshwater turtles to show that community-based management can catalyse a rapid and widespread continental scale recovery across Amazonia. We first discuss sustainable levels of harvest, and then explore how community-based management can result in rapid population recovery trajectories for *P. unifilis*, providing future projections based on human population growth and prioritized conservation actions.

Adult survival is important for the conservation of freshwater turtles, yet as reported for other overexploited wildlife species a relatively young age at reproductive maturity is a critical element for widespread and rapid population recovery (Bodmer *et al.* 1997; Campos-Silva and Peres 2016; Dickey-Collas *et al.* 2010; Shine and Harlow 1999; Spencer *et al.* 2017). We found that increasing first-year survival could generate rapid population increases and even compensate for population losses due to adult harvesting. The long-lived *P. unifilis* is relatively fast maturing, with 5 year-old females laying eggs, which is a similar maturation age to other commercially exploited Amazonian wildlife species such as the giant freshwater fish *Arapaima gigas* (Campos-Silva and Peres 2016) and non-timber forest products such as açai fruits (*Euterpe oleraceae*) (Weinstein and Moegenburg 2004). This relatively short time to reproductive maturity contrasts with the slower maturing temperate and larger-bodied marine turtles (Spencer *et al.* 2017). The potential of demographic differences to drive the success of specific management actions is a clear example of where policies for widespread recovery must be informed by insights generated from relevant species models.

Nesting area protection (under local CBM initiatives) can be an effective strategy to enable rapid and widespread recovery for *P. unifilis*. Our scenario comparison showed increased population sizes through headstarting (increasing first-year survival), with population doubling time halved (reduced from 39 to 14 years) when first-year survival increased from 0.2 to 0.3. Our models indicate that headstarting results in the number of adult females increasing and with first-year survival of at least 50%, the adult population could double within 8 years. Thus, under the CBM scenario it would be possible to induce rapid population recovery across the pan-Amazonian distribution of this freshwater turtle. A focus on species management can be more efficient than a focus on directly reducing the negative effects on a specific life-history stage

(Spencer *et al.* 2017). Moreover, *P. unifilis* females mature much quicker than some of its congeners (Vogt 2008) and increases in first-year survival via headstarting can therefore generate rapid changes in later life stages such as early-late juveniles and adults. Thus, the measurable benefits of boosting first-year survival, such as a 50% increase in adult females can be rapidly achieved (i.e. within a decade) for this overexploited freshwater turtle.

Both the expansion of new development frontiers and growing energy and food demands can cause drastic reductions in freshwater turtle populations across Amazonia (Castello *et al.* 2013; Moll and Moll 2004; Norris *et al.* 2018a; Smith 1979). Increased resource demands from growing human populations can be directly linked with infrastructure development, including electrification of rural communities and hydroelectric dams (Castello *et al.* 2013; Tundisi *et al.* 2014). Such changes mean that physical accessibility will undoubtedly change in remote Amazonian areas over the next decades. The number of urban inhabitants will increase, but not all urban areas will necessarily spread/expand geographically. In fact, there is little evidence to suggest substantial short to mid-term urban expansion across the *P. unifilis* distributional range (Seto *et al.* 2012). However, the impacts of natural resource demands from urban inhabitants can extend 1000´s of kilometres (Tregidgo *et al.* 2017), which could affect the currently inaccessible areas across Amazonia.

The establishment and maintenance of protected areas has been the priority for pan-Amazonian biodiversity conservation, yet it can take decades for newly established protected areas to meet minimum management effectiveness criteria. Although actions to encourage social integration are recognised as key for conservation success, outside of Indigenous lands social integration remains a secondary/complementary component to protected area establishment and maintenance. For example, after an investment of hundreds of millions of dollars in the creation and consolidation of protected areas across the Brazilian Amazon, the median overall management effectiveness score obtained for 114 PAs (covering 592,000 km^2 of Brazilian Amazonia) was 0.62 (WWF 2017), which represents management described as “basic but with major deficiencies” (Leverington *et al.* 2008). Perhaps even more surprisingly, within this globally important multi-million dollar program there remain only recommendations for the inclusion of “specific indicators of social and economic impact for incorporation into ARPA’s monitoring protocol” (WWF 2017).

Our finding that CBM can work better than the more widely extolled protected area model suggests that a reassessment of priorities for the development of effective pan-Amazonian conservation actions is necessary. Our Business-as-Usual scenario reflects the pessimistic evaluation that neither protected areas, national water resource legislation, nor community-based management schemes can adequately protect Amazonian freshwater ecosystems against current pressures (Castello et al. 2013). Yet, projections from both Protection and Community-Based Management scenarios clearly demonstrate the potential of conservation policies to generate widespread recoveries of managed species across their freshwater ecosystems. The continued challenges to improve protected area effectiveness mean that CBM is an increasingly necessary requirement for conservation success. We found that under BAU scenarios populations can collapse within the decades necessary for PAs to become effectively managed. The Peruvian Amazon and Venezuelan Llanos were clear examples of regions that were both largely accessible and poorly protected. The adoption of CBM in Peru is a clear demonstration of the effectiveness of such approaches to generate rapid population recoveries and conservation success (Harju *et al.* 2017; Sinovas *et al.* 2017). But how can Community-based management effectively operate across 123,694 km of rivers that are accessible and unprotected?

With 57% (representing a cumulative length that would stretch three times around the globe) of rivers accessible and unprotected CBM becomes vital for pan-Amazonian conservation efforts. A diverse range of policies, governance regimes and management actions have been used successfully for the local scale conservation of freshwater turtles outside of protected areas (Harju *et al.* 2017; Moll and Moll 2004; Sinovas *et al.* 2017; Spencer *et al.* 2017). The major challenge is to translate these local conservation gains to more widespread recoveries. As found in many species, *P. unifilis* has a clustered distribution along rivers (Coway-Gomez 2007; Escalona and Fa 1998; Ferreira and Castro 2010; Moll and Moll 2004). This clustered distribution pattern enables strategically localised and targeted actions to generate widespread impacts. For example, CBM at only two nesting areas enabled the successful protection of 75% of nests along a 33 km stretch of river (Norris *et al.* 2018b). The coverage required to generate population recoveries can therefore be achieved by relatively simple actions at strategic locations that represent a fraction of the overall river length. Additionally, the fact that CBM is necessary along accessible pan-Amazonian rivers creates substantial opportunities for widespread and integrated conservation solutions. Advancing education is a priority across all nine countries and more accessible rivers are closer to academic and research centres. Therefore this physical proximity immediately generates opportunities for adaptive multilevel management options.

We examined the conservation potential of three scenarios for future projections of a tropical freshwater turtle species ubiquitously distributed across Amazonia. Our community-based management scenario could increase first-year survival and consequently number of adults, which in turn would result in rapid increases in population levels across the distributional range. Protected areas can be successful relative to other conservation targets, but they will often still fall short of meeting minimum criteria for sustaining natural resources and biodiversity retention. Local community engagement is necessary and perhaps the only way forward to ensure long-term conservation objectives for overexploited wildlife species in low-governance tropical regions like the Amazon. Our projections of widespread demographic population increases of freshwater turtles associated with community-based management reveals a road to recovery for imperilled turtles and other aquatic vertebrates, outlining a potential success for 21st century biodiversity conservation.

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