

FULL TEXT:

- Rasal, V., Everard, M., Khandal, D., Chandrawal, K. and Sahu, Y.K. (*in press*). Valuation of the ecosystem services provided by the Kailadevi Wildlife Sanctuary, Rajasthan, India. PARKS, *in press*.

## Valuation of the ecosystem services provided by the Kailadevi Wildlife Sanctuary, Rajasthan, India

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#### **Abstract**

Kailadevi Wildlife Sanctuary (KWLS), in Rajasthan (India), lost its tiger population in 2000, though since 2019 tigers have over-spilled from the adjacent Ranthambhore National Park (RNP). Though protected, the forests of KWLS are depleted through exploitation by resident and migratory human communities. This study is novel in addressing ecosystem service flows and values of an Indian wildlife sanctuary on a systemic basis, supported by substantial primary fieldwork, illuminating the many societal values it generates. A VALUE+ approach used local interviews, primary fieldwork and literature to determine ecosystem service provision by KWLS, where possible with monetary representation. Conservative values estimated for 21 ecosystem services covered: (1) benefit flows at INR 84.47 billion year<sup>-1</sup>; (2) natural capital stock at INR 367.3 billion; and (3) unquantified ecosystem services. Monetary values are purely illustrative representations largely based on surrogate markets, but nonetheless indicate the range and scale of mainly unappreciated societal benefits. Comparison of KWLS with RNP illustrates differences in service provision between lesser and highly protected ecosystems, including the potential to enhance services such as ecotourism and space for reestablished tiger and other wildlife populations but also potential disbenefits for those currently extracting resources from KWLS who may become displaced or require compensation.

#### **Key words**

Kailadevi; Ranthambhore; tiger; livelihoods; Rajasthan; VALUE+

#### **Research highlights**

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- Kailadevi Wildlife Sanctuary provides diverse, mainly unappreciated benefits
- Values derived for 21 ecosystem services were conservatively estimated
- Recognition and quantification of these benefits can support policy development
- Quantifiable flows were worth INR 84.47 billion yr<sup>-1</sup> and stock at INR 367.3 billion
- More protection would support tigers and improve some benefits including ecotourism

#### **Standfirst**

*“The forest is a peculiar organism of unlimited kindness. It affords protection to all beings, offering shade even to the axe who destroys it.”*

- Gautama Buddha

## **1. Introduction**

Recovering tiger (*Panthera tigris*) numbers in Ranthambhore Tiger Reserve (RTR), Rajasthan state (India), have resulted in animals moving into the adjacent Kailadevi Wildlife Sanctuary (KWLS). KWLS historically supported tigers, though its forests were extensively exploited until declared a Wildlife Sanctuary in 1983 and, in 1991, its inclusion in the Tiger Project, Ranthambhore (Kothari *et al.*, 1997). Continuing ecological decline included complete loss of tigers by 2000 (Singh & Reddy, 2016). Increasing human and livestock encroachment intensified degradation, social unrest and conflict between local villagers and migratory grazers. Reappearance of tigers in KWLS from 2011, initially intermittent but later including sightings of a tigress with 2 cubs in 2018 (personal communication, Forest Department staff) highlights the importance of improved protection of KWLS for tiger recolonisation.

Enhanced protection can also deliver a diversity of additional societal benefits. For example, India’s Tiger Reserves collectively encompass 2.1 per cent national area yet constitute sources for around 300 rivers, supporting water and food security across substantial downstream areas. Villages established in and adjacent to KWLS may also potentially benefit from income from tiger tourism. However, there are conflicting views about the different values provided by protected areas (PAs). Conservation of ecosystem services is increasingly incorporated into PA goals, potentially improving co-management for biodiversity and ecosystem services (Floris *et al.*, 2020; Li *et al.*, 2020). A broadened focus encompassing ecosystem services can help resolve the interests of people and biodiversity within conservation approaches. However, currently, species richness and regulating services (particularly carbon storage and water yield) are often addressed though provisioning services are underrepresented in many African PAs (Wei *et al.*, 2020) and stringent measures in many protected areas

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can generate inequalities of access to cultural services (Martinez-Harms *et al.*, 2018). Refocusing management of PAs to include sustainable uses of ecosystem services promoting the development of local communities remains understudied (Zhang *et al.*, 2020), notwithstanding the long-established 'wise use' principle resolving human needs with maintenance of ecological character under the Ramsar Convention (Pritchard, 2018).

Valuation of ecosystem services from 6 of India's Tiger Reserves (Corbett, Kanha, Kaziranga, Periyar, Ranthambore and the Sundarbans) using the VALUE+ approach concluded they provided US\$769-2,923 ha<sup>-1</sup> year<sup>-1</sup> of quantifiable socio-economic benefits (Verma *et al.*, 2015 and 2017). Khanna *et al.* (2015) and Bhagabati *et al.* (2015) presented a strong economic case for conservation of KWLS forest, and Everard *et al.* (2017) recommended protection of corridor habitats between RTR and KWLS to improve wildlife movement and alleviate wildlife-human conflict. Average monetised ecosystem services benefits of INR (Indian ₹) 3,300 were calculated for households peripheral to Rajasthan's Sariska Tiger Reserve (Sekhar, 1998). For KWLS to be elevated to a fully protected reserve, it would be necessary to remove substantial human interference. For this purpose, assessment of the diversity of ecosystem services it provides can determine consequences for overall value, including disbenefits to local stakeholders who may require compensation.

Ecosystem service evaluation is becoming established in addition to traditional biodiversity conservation approaches to inform evidence-based policy and management decisions (Lele *et al.*, 2013; Börger *et al.*, 2014). However, economic valuation represents a subset of ecosystem services, many of which remain inherently incommensurable with financial values (Schmidt *et al.*, 2016). Innovative methods are necessary to address knowledge gaps and to account for less tangible benefits from pro-conservation efforts (Everard & Waters, 2013; Emerton *et al.*, 2006). The IPBES approach (Pascual *et al.*, 2017) recognises that nature is perceived and valued in starkly differing and often conflicting ways by different constituencies, proposing an inclusive valuation of nature's contributions to people (NCP) in decision making spanning intrinsic, instrumental and relational values, addressing power relations among different perspectives. However, this is not without practical difficulties, for example Ye *et al.* (2020) proposing an ecosystem intrinsic value (EIV) metric based on factors such as mechanistic factors as exergy and 'eco-energy' to avoid the subjectivity of methods such as 'willingness to pay', but which is at odds with conceptions of the intrinsic value of wild species (Vucetich *et al.*, 2015).

This research is necessary to assess and communicate the diverse values derived from KWLS and their distribution across broad proximal and more distant stakeholder groups, some of whom may formerly have been overlooked, and how these may inform decisions pertaining to future management. This is important as optimisation of benefits to people as well as wildlife in conservation strategies can identify new incentives and funding sources for biodiversity conservation (Wei *et al.*, 2020). This study follows the VALUE+ approach used by Verma *et al.* (2015 and 2017), deriving conservative estimates for 21 ecosystem services. 'VALUE' denotes economic

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valuation and '+' reflects where monetisation is currently not possible. Value+ is based on the Millennium Ecosystem Assessment (2005) framework of ecosystem services, rather than IPBES or other more recent frameworks. However, this approach is justified as it has been applied not only to the adjacent RTR but also more widely, reflecting high proportions of non-marketed services in the combined total values of services (for example Barua *et al.*, 2020), and also in demonstrating linked socio-ecological costs associated with recovery of keystone predators (Gregr *et al.*, 2020). Most Indian ecosystem service valuations are based on secondary data and satellite images (Lakerveld *et al.*, 2015; Jadhao *et al.*, 2017; Verma *et al.*, 2015). By contrast, this study uses extensive fieldwork supporting quantitative and qualitative assessment of ecosystem services.

### The study site

KWLS (Karauli District, Rajasthan state) lies between latitudes 26°2' N and 26°21' N and longitudes 76°37' E to 77°13' E spanning 672.82 km<sup>2</sup> (Pathak, 2009), 401.63 km<sup>2</sup> of which is defined critical tiger habitat (CTH) of the RTR (Forest Department, Rajasthan, 2015). Climate is semi-arid with average annual rainfall of 750-800mm, about 90 per cent falling during the July-September monsoon season, with temperatures of 2-15°C in winter (November-February) and exceeding 47°C in summer with frequent droughts (Forest Department, Rajasthan, 2015). KWLS forms a northern boundary of the Ranthambore National Park (RNP) (Figure 1), separated by the River Chambal corridor that forms an important route for animal movements between protected areas (Thorat & Gurjjer, 2010; Forest Department, Rajasthan, 2015).

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Figure 1: Map of Kailadevi Wildlife Sanctuary (© Tiger Watch)



The KWLS terrain is characterised by confluence of the Aravalli Hills and Vindhyan Hills system (Kothari et al., 1997), comprising table-top plateaus ('dang') with parallel ridges forming deep gorges ('khoh') hosting rich forest and soil, high moisture and cooler temperatures. The main khoh in Kailadevi are Nibhera, Kudka, Chiarmul, Ghanteshwar, Jail and Chidi (Das, 2011). Towards the Chambal River, there are 5-8 km wide patches of ravines up to 35-50 m deep (Thorat & Gurjjer, 2010). GIS analysis reveals that 148.28 km<sup>2</sup> is dhonk forest, 98.83 km<sup>2</sup> is mixed forest in khoh, 2.42 km<sup>2</sup> is encroached human habitation and 34.24 km<sup>2</sup> is farmland. These forests protect the watershed of the Chambal and Banas Rivers (Forest Department, Rajasthan, 2015; Thorat & Gurjjer, 2010).



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Figure 2: Image of a khoh



Vegetative cover elsewhere in KWLS is relatively sparse. Dhonk (*Anogeissus pendula*) is the dominant tree, constituting 80 per cent vegetation cover. Forests adjacent to villages and the forest boundary are reduced to stunted shrubs through anthropogenic pressures (Forest Department, Rajasthan, 2015; Thorat & Gurjjer, 2010). Larger fauna includes predators such as Leopard (*Panthera pardus*) and herbivorous prey populations including various deer species. For management purposes, KWLS is divided into four Ranges: Kela Devi; Karanpur; Mandrail; and Nainiyaki (Forest Department, Rajasthan, 2015).

Rock paintings reveal human occupation of Kailadevi Forest since prehistoric times. Today, KWLS hosts pastoral and agricultural communities substantially dependent on forest resources for their livelihoods. Currently, there are 66 villages in KWLS, each grazing a specific forest area known as a 'kankad'. During and immediately after the monsoon (July-October), people from nearby villages move livestock into KWLS to exploit fresh fodder, forming cattle camps known as 'khirkadi' (Forest Department, Ranthambhore, 2015). Villages inside and peripheral to the forest exert substantial biotic pressure through extraction of timber, fodder and other resources. Wildlife tourism is almost absent due to sparse charismatic fauna and tourism facilities, though many pilgrims visit temples in the Sanctuary.

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## Methods

Evaluation methods, both monetary and non-monetary, must be relevant to context, management need and resources (Turner *et al.*, 2016). We follow Verma *et al.* (2017), working closely with key stakeholders and experts, interrogating relevant literature and applying value transfer where relevant. Economic valuation techniques have their critics, for example Menon and Rai (2019) specifically criticising use of VALUE+ applied to India's Tiger Reserves as a neoliberal attempt hiding complex human-nature relationships and the rights of people living within them. We nevertheless outline who the key beneficiaries of services are and the nature of benefits. Methods for assessing ecosystem services spanning broad ecosystem service categories are summarised in Table 1, and elaborated in the [Supplementary Material](#).

Table 1: Summary of methods for assessing ecosystem services

<b>Broad ecosystem service categories</b>
<ul style="list-style-type: none"><li>• <b>Methods use to assess specific ecosystem services</b></li></ul>
<p><i>Fodder-related ecosystem services</i> ecosystem services are important, villagers within and adjacent to KWLS as livestock plays an important role in India's economy:</p> <ul style="list-style-type: none"><li>• Socioeconomic survey: livelihood, community structure and dependencies on agriculture and livestock were recorded by surveying every household in the 66 villages and 20 livestock keepers in every forest Range. Livestock numbers were converted into Adult Cattle Units (ACUs) following Singh <i>et al.</i> (1993).</li><li>• Fodder availability: Assessed major sources included leaves of dhonk trees, seasonal grasslands and crop residues, and minor sources included fodder crops, oil cake, weeds in fields, and forage cultivation.</li></ul>
<p><i>Timber and fuelwood-related ecosystem services</i>, of value to local people within and adjacent to KWLS despite the forests being depleted. Although technically illegal, these benefits are being realised and so are relevant for estimation of the monetary compensation needed for local stakeholders to match the benefits they currently derive from the area:</p> <ul style="list-style-type: none"><li>• Timber stock: Timber extraction is banned, so timber stock was calculated to illustrate scale of potential value based on random surveys covering three principal types: (1) Tropical Dry Deciduous Forests dominated by dhonk; (2) mixed deciduous khoh (gorge); and (3) ravine scrubland forests, converting to bole volume and converting to economic value following Verma <i>et al.</i> (2015).</li><li>• Wood extraction: Though also technically illegal, wood extraction remains a primary fuel source for people living in and adjacent to KWLS. Fuelwood and</li></ul>



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other biomass (dung cake, agriculture residues, etc.) consumption by villages was quantified in 15% of randomly selected villages.
<p><i>Carbon stock and sequestration ecosystem services</i>, of value to the global community through climate stabilisation:</p> <ul style="list-style-type: none"><li>• Carbon stock: Field surveys of tree standing crops in the four forest Ranges informed calculation of above-ground carbon content after Rajput <i>et al.</i> (1996), Limaye and Sen (1956) and (McGroddy <i>et al.</i> 2004), and of below-ground biomass after Ramankutty <i>et al.</i> (2007).</li><li>• Annual grassland carbon sequestration: Grassland productivity assessment was converted to carbon content after Penman <i>et al.</i> (2003).</li></ul>
<p><i>Soil-related ecosystem services</i> were based on erosion calculated using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), beneficial to communities downstream in catchments served by KWLS and within the KWLS through productivity:</p> <ul style="list-style-type: none"><li>• Sedimentation: Assessed by valuation of downstream sedimentation avoidance, based on offset costs of dredging after Verma <i>et al.</i> (2015).</li><li>• Nutrient retention: Assessed using commercial fertilizer replacement costs.</li></ul>
<p><i>Water-related ecosystem services</i>, beneficial to surface and groundwater users adjacent to the KWLS perimeter including supporting fish production:</p> <ul style="list-style-type: none"><li>• Water volume within KWLS: Stock value was assessed by extrapolating volumes stored in impoundments within KWLS with average canal irrigation water rates in Rajasthan (Central Water Commission 2017).</li><li>• Water volume outside KWLS: An assumed 50% contribution to water stored in four dams dependent on streams draining from KWLS was multiplied by canal irrigation water rates.</li><li>• Groundwater recharge: KWLS serves as a groundwater catchment vital for adjacent communities, assessed quantitatively and economically based on land cover categories.</li><li>• Fish productivity: Data for fish production in Sawai Madhopur district obtained from FAO (2009) was multiplied by the price of table fish in local markets.</li></ul>
<p><i>Tourism ecosystem services</i>, beneficial to tourist but with income realized by tourism operators and local involved communities:</p> <ul style="list-style-type: none"><li>• Travel-cost methods (Clawson and Knetsch 1966) were used to estimate economic value at five religious sites (Ghanteshwar, Kudaka Math, Maheshra Kho, Kailadevi cave, and Kedar-Baba Khoh), informed by key informant interviews and focus group discussions (FGDs).</li></ul>
<p><i>Qualitatively described ecosystem services</i> are not inherently monetizable, of relative significance for intrinsic values as well as adjacent pollination and non-</p>

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timber forest product (NTFP) beneficiaries was informed by literature review, discussions with local and international experts, and community consultations:

- Pollination services: Significant for agriculture and food security, but lacking quantitative methods relevant to KWLS.
- Genetic resources: Significant but not inherently quantifiable.
- NTFPs: Diversity and approximate scale extracted from KWLS were assessed based on community surveys.

*Miscellaneous ecosystem services*, related generally to intrinsic values as well as local and adjacent beneficiaries of disease and pollination services

- Inherent values for KLWS gene pool, pollination services, natural pest and disease regulation, atmospheric gas regulation, waste assimilation and provision of habitat for wildlife and refugia were transferred from Verma *et al* (2015).

### 3. Results

Ecosystem services quantified and valued or simply recognised qualitatively are documented in the following sub-sections, and described in greater detail in [Supplementary Material](#).

#### 3.1 Fodder-related ecosystem services

The socioeconomic survey revealed seasonally variable grazing, yielding direct benefits to livestock owners ([Supplementary Material, S1](#)). 80% of villager cattle spend 10 months and feral cattle typically spend 8 months within KWLS, and domestic cattle from nearby villages are brought in between July to October by kirkadis (cattle camps). Total ACU grazing in KWLS was calculated as 50,288.4 requiring (at 6.5 kg per day per ACU) 76,993.72 tonnes year<sup>-1</sup> fodder.

- Dhonk leaf biomass production was estimated at 9,619.81 tonnes, with total value estimated of 19.23 million Rupees year<sup>-1</sup>. Owing to the slow growth of the forest – unlike that of grassland, straw, small-scale cropping and weed harvesting – there is need to control overharvesting to protect other ecosystem services flowing from forested plateaus.
- Total standing dry above-ground biomass of grassland was calculated at 1.94 tonnes ha<sup>-1</sup>, a low grassland productivity attributed to heavy grazing and subsequent loss of soil and nutrients. Available grassland fodder dry weight was calculated at 2.480 ha<sup>-1</sup> year<sup>-1</sup>, with a total economic value (multiplying by grassland area and INR 4 kg<sup>-1</sup>) of INR 343.19 million. Grazing pressure is 50% higher than the recommended stocking limit of 1 ACU per hectare (Planning Commission, 2011), threatening ecosystem structure, functioning and

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conservation (Eldridge *et al.*, 2016).

- Straw production was estimated at 11,219.09 tonnes year<sup>-1</sup> broken down between wheat, paddy and bajara, with a total annual economic value of 44.87 million Rupees.
- Production of oilcake from mustard (1,056 kg ha<sup>-1</sup>) and sesame (326 kg ha<sup>-1</sup>) was calculated as worth 6.91 INR million year<sup>-1</sup>.
- Green weed production (0.1 tonnes ha<sup>-1</sup> year<sup>-1</sup>) was multiplied by field area in KWLS, deriving a quantity of 284.94 tonnes year<sup>-1</sup>. Multiplying by a local market price of INR 2,000 tonne<sup>-1</sup> yields an economic value of INR 0.56 million year<sup>-1</sup>.
- An average of 2 ha of land cultivated for forage crops in 8 villages implies a total of 16 ha, multiplied by unit kasani production rate (9 kg ha<sup>-2</sup> year<sup>-1</sup>) to derive total production of 108 tonnes year<sup>-1</sup>. Based on local market price of 2,400 Rupees tonne<sup>-1</sup>, economic value is 0.26 million Rupees year<sup>-1</sup>.

Integrating all sources of fodder supply produced in KWLS provides aggregate annual economic value of 415.02 million Rupees year<sup>-1</sup>, though livestock pressures suppress optimum growth of fodder species and wider ecosystem services production including habitat for wild herbivores.

### 3.2 Timber and fuelwood-related ecosystem services

Field sampling of standing wood volume in KWLS and value transfer from Verma *et al.* (2017) estimates a standing crop of 1,204,542 m<sup>3</sup> with a value of INR 34 billion (Supplementary Material, S2).

Though illegal, wood extraction is important for local people for construction and as fuelwood for cooking, heating and the production of mava (condensed milk).

- Poles is extracted for construction of houses, barn and cattle sheds, fencing, making agricultural and household, and furniture, yielding direct benefits to users. Dhonk is the preferred, durable wood. Household surveys revealed average household use of 10-12 wooden poles year<sup>-1</sup>, with the wood volume of 10 poles calculated as 0.159 m<sup>3</sup>. Multiplying by the 2,663.75 families within KWLS determined by household surveys, approximately 423.53 m<sup>3</sup> of small timber worth 12.01 million Rupees is extracted annually.
- Field assessment found fuelwood consumption of 7,617.44 tonnes year<sup>-1</sup>, worth INR 38.08 million, representing an averted cost for procuring other fuel sources. Socioeconomic surveys found that 55% of fuelwood is used for mava-making by communities heavily dependent on cattle but lacking ready markets necessitating conversion to mava and ghee. One kg of mava is produced from 4 kg milk, requiring 10 kg wood. An average 2 kg mava day<sup>-1</sup> is produced by every family, aggregating to 1,710 kg day<sup>-1</sup> (250 days production

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annually reflecting seasonal variability). Mava is sold at INR 30 l<sup>-1</sup>, the same as milk from the local dairy, despite substantial inputs of human labour and fuelwood, representing a loss-making enterprise with substantial negative effects on forest resources. Impact could be limited by: (1) subsidies for dairy collection from remote villages; (2) establishing milk collection centres; or (3) payments for protecting wood resources.

- Other fuels used include agricultural residues (considered negligible inside KWLS), cow dung cake (only a small level of consumption was found by survey at 0.65 kg day<sup>-1</sup> or 237.25 kg year<sup>-1</sup>), and LPG cylinders (low uptake due to lack of refilling stations and cultural beliefs including taste of food).

### 3.3 Carbon stock and sequestration ecosystem services

Carbon stock and sequestration was quantified in different forest types and grassland in KWLS, represented in monetary terms in terms of global socioeconomic benefit but lacking direct benefits to local communities (*Supplementary Material, S3*).

- Total carbon in dhonk forest, based on biomass values from Verma et al. (2015), was 19.99 t C ha<sup>-1</sup>. A 14,828 ha of dhonk forest therefore stores 0.62 million tonnes carbon, worth 493.93 million Rupees. Consequently, sequestration potential is 8,748.52 tonnes carbon year<sup>-1</sup>, with estimated value of INR 6.86 million year<sup>-1</sup>.
- Total carbon in ravine forest was 26.22 t C ha<sup>-1</sup>, 31.16% higher than dhonk forest. A 3,700 ha of ravine scrubland therefore stores 0.25 million tonnes carbon, worth 200.76 million Rupees. Consequently, sequestration potential is 4,612.8 tonnes of carbon year<sup>-1</sup>, with estimated value of 3.617311632 INR million year<sup>-1</sup> transferring sequestration values from Verma et al. (2015). Generally, ravines are considered by planners as 'wastelands', often flattened for agriculture and other uses, yet they provide habitat diverse wildlife, serve as wildlife corridors especially outside protected area (Khandal and Khandal 2013) and this study highlights their importance for productivity.
- Total carbon in khoh forest was 78.19 t C ha<sup>-1</sup>, exceeding both dhonk and ravines. 9,883 ha of khoh forest therefore stores 1.19 million tonnes carbon, worth 936.14 million Rupees. Consequently, sequestration potential is 16,899.93 tonnes of carbon year<sup>-1</sup>, with estimated value of 13.25 INR million year<sup>-1</sup> based on a social cost of carbon of 11 \$ tonne<sup>-1</sup> at 4% discount rate for 2015 (EPA, 2016).
- Carbon stock in seasonal grassland was calculated as 1.19 million tonnes, valued at 939.77 million Rupees. Seasonal grasslands of the KWLS sequester 80,61 tonnes of carbon year<sup>-1</sup>, worth 63.21 million Rupees year<sup>-1</sup>. The KWLS seasonal grassland is heavily modified by intensive grazing and tree cutting; habitat protection would increase carbon sequestration and other ecosystem service flows.

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Total carbon stock in the KWLS estimated at 2.08 million tonnes with an economic value of 2,570.629 million Rupees. Total estimated annual carbon sequestration was estimated at 0.11 million tonnes year<sup>-1</sup>, with an economic value of 86.94 million Rupees year<sup>-1</sup>. Carbon stock and sequestration rates in the KWLS are low compared with studies from similar forest types elsewhere, suggesting heavy pressure from grazing and wood extraction, and taking account of harsh natural conditions.

### 3.4 Soil- and water-related ecosystem services

Soil-related ecosystem service assessments (Supplementary Material, S4), beneficial to communities in downstream catchments as well as users of on-site productivity, include:

- Soil retention was not directly valued, but inform economic valuation of avoided off-site costs from sedimentation and nutrient loss.
- Sedimentation avoidance from the KWLS was calculated as 80,621.7 m<sup>3</sup> year<sup>-1</sup> with a total economic value of INR 4.701 million year<sup>-1</sup>.
- Soil nutrient retention, determined by multiplying soil nutrient concentration with loss avoided (erosion regulation) and multiplying by the costs of alternative fertiliser inputs yielded an estimated nutrient retention value of KWLS at 85.92 INR million year<sup>-1</sup>. (5.95, 0.43 and 79.54 INR millions respectively for nitrogen, phosphorus and potassium).

Water-related ecosystem service assessments, beneficial to communities in downstream catchments, include:

- Water volume within the KWLS, estimated by adding cumulative surface area of pangara (3.26 km<sup>2</sup>) and a small masonry reservoir located at Kalyanpura (2.1 km<sup>2</sup>), multiplied by canal irrigation water costs yielded a value of 0.16 million Rupees. If consumed within a year, this also represents an annual benefit value.
- Water volume in reservoirs outside KWLS dependent on the Sanctuary, allowing for complete dependence of the Needhar dam and a 50% contribution to Kalisil Reservoir, Mamchari Dam and Atewa Dam, yielded a total estimated economic value of irrigation water from KWLS of 0.61 million Rupees year<sup>-1</sup>.
- Groundwater recharge increased by KWLS was estimated at 40.17 million m<sup>3</sup> year<sup>-1</sup>, valued at 823.16 million Rupees year<sup>-1</sup>.
- Fish productivity in dependent dams was calculated as 34,960 kg year<sup>-1</sup>, worth 0.34 million Rupees year<sup>-1</sup>.

Soil- and water-related ecosystem services provided by KWLS total 914.86 million Rupees year<sup>-1</sup>.



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### 3.4 Tourism ecosystem services

Focus group discussions revealed approximately 52,980 tourist visits to the five selected temples year<sup>-1</sup>, most tourists coming from nearby villages and small towns though the Kedar Baba temple is visited by more remote pilgrims (Supplementary Material, S5). Aggregated travel costs derived a value of INR 6,894,000 year<sup>-1</sup>, reflective of how much visitors value visiting the area rather than direct benefits to local stakeholders.

Tourists also exert pressures, including large quantities of plastic waste and contamination of water sources. These pressures require management responses to protect fragile khoh habitats.

### 3.6 Qualitatively described ecosystem services

‘Qualitatively described’ services include those that relate to the status of the ecosystem and, at least under the Millennium Ecosystem Assessment (2005) framework, may be expressed in biophysical but not monetary terms. Values for pollination, genetic diversity and non-timber forest products could not be quantified in this study (Supplementary Material, S6).

- 2,551.07 ha in the KWLS were found by surveys to be under cultivation in the kharif season, with 1,749 ha cropped in the rabi season. Cereal grains dominate but mostly dependent on wind pollination. Household surveys found a range of kharif and rabi crops benefitting from insect and other pollinators, but no studies relevant to the KWLS ecosystem were available and field experiments could not be accommodated in this study. The pollination service is therefore described qualitatively.
- Genetic diversity (gene pool) within any ecosystem represents a rich and co-evolved resource, but no attempt was made to try to assign value to flora and fauna beyond supporting documentation based on rapid surveys of the biodiversity of the KWLS.
- Villages and settlements in KWLS are highly dependent on NTFPs including wild fruits (Ber, *Grewia*, Carandas, etc.) asparagus roots, *Grewia tenax* sticks, *Ocimum basilicum* seeds, gum, medicinal plants, and plant fibre. Socioeconomic surveys also revealed substantial illegal extraction (poaching) of *Asparagus* roots, *Grewia tenax* sticks and *Ocimum basilicum* seeds by groups of poachers crossing the Chambal river from the neighbouring state of Madhya Pradesh and camping for a number of days to collect these NTFP materials.

### 3.7 Miscellaneous ecosystem services

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Table 2 records values for miscellaneous other services provided by KWLS transferred from the Verma *et al* (2015) study of the adjacent Ranthambhore division of RTR, correcting for area differences. These six miscellaneous services – gene-pool protection, pollination-related services, habitat for wildlife services, biological control of diseases and pests, aggregated gas regulation services, and breakdown of waste products – have a cumulative value of INR 6,979.81 million year<sup>-1</sup> (Supplementary Material, S7).

Table 2: Values for miscellaneous ecosystem services provided by KWLS

Ecosystem services	Indicative economic value (transferred from Verma <i>et al</i> (2015), correcting for area differences)
Gene-pool protection	INR 6,124 million Rupees year <sup>-1</sup>
Pollination-related services	INR 121.10 million Rupees year <sup>-1</sup>
Habitat for wildlife services	INR 157.44 million Rupees year <sup>-1</sup>
Biological control of diseases and pests	INR 44.4 million Rupees year <sup>-1</sup>
Aggregated gas regulation services	INR 48.44 million Rupees year <sup>-1</sup>
Breakdown of waste products	INR 484.43 million Rupees year <sup>-1</sup>
<b>Cumulative value of miscellaneous services provided by KWLS</b>	<b>INR 6,979.81 million year<sup>-1</sup></b>

#### 4. Discussion

Assessment of 21 ecosystem services illustrates the systemically interconnected, multiple values provided by KWLS. These include service flows of INR 12.55 million km<sup>-2</sup> year<sup>-1</sup>; natural capital stock of INR 367.3 billion; and intangible services without ascribed values. Monetisation is largely illustrative of the range and scale of societal benefits, some of which is tangible for local users of resources whilst others demonstrate more wide-scale indirect benefits to wider constituencies beyond, and sometimes distant from, the Sanctuary boundary.

Demonstration of this multiplicity and illustrative scale of values is significant for communication of the wider importance KWLS, consistent with the wider uptake of ecosystem service conservation within PA goals (Floris *et al.*, 2020; Li *et al.*, 2020). Evaluation highlights direct benefits from current resource extraction from KWLS that may be curtailed under conservation management, and may therefore require compensation. It also identifies benefits to distal stakeholders, such as users of streams, dams or groundwater peripheral to KWLS, who may not currently recognise themselves as beneficiaries of the PA.

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Comparison of flow and stock values generated by KWLS using primary data with those assessed for the adjacent Ranthambhore division of the RTR based on secondary data (Verma *et al.*, 2015) can provide insights about likely changes in overall benefits and their distribution if KWLS is taken into more stringent conservation management (Table 3). RTR has a strong tiger population and statutory designation, and has in place better protection and management structure. Differences between values for RTR and KWLS indicate current biotic pressures on KWLS. They also suggest significant potential to increase the capacities of KWLS to support wildlife, potentially enhancing a range of ecosystem service benefits across a spectrum of geographical scales whilst also reducing other services.

*Table 3: Comparison of assessment of ecosystem services between KWLS (this study) and RTR (Verma et al. 2015)*

Services	KWLS, from this study (INR millions yr <sup>-1</sup> , or INR millions for stock values)	RTR, from IIFM study (INR millions yr <sup>-1</sup> , or INR millions for stock values)
<b>Study area</b>	<b>672.8 km<sup>2</sup></b>	<b>780 km<sup>2</sup></b>
<b>Flow services</b>		
Carbon	86.943	63.92
Fuel wood	38.08	Not assessed
Soil loss avoidance	4.7	9.32 (after adjustment of error)
Soil nutrient	85.92	169.3 (after adjustment of error)
Groundwater	823	1,153.7
Water stored	0.74	Not assessed
Fish	0.34	Not assessed
Fodder	415.02	Not assessed
Pollination	121.10	140.4
Gene pool	6,124.01	7,100.00
Habitat	157.44	182.52
Biological control	44.40	51.48
Gas regulation	48.44	56.16
Religious tourism	6.8	Not assessed
Waste assimilation	484.43	561.6
<b>Total flow services</b>	<b>INR 84.41 billion yr<sup>-1</sup></b>	<b>INR 94.88 billion yr<sup>-1</sup></b>
<b>Stock services</b>		
Carbon stock	2.570	5.010

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Timber stock	34.1	44.190 (after adjustment of the error)
<b>Total stock services</b>	<b>INR 36.6 billion</b>	<b>INR 49.2 billion</b>

This information can collectively inform management decisions about KWLS, supporting a business case for greater ecosystem protection. This case may include decisions to exclude damaging human interventions from the Sanctuary such as the extensive use of the provisioning services of fodder and fuelwood, which appears to compromise soil and biomass carbon sequestration and water-vectored services, for which some degree of compensation or livelihood alternatives may be necessary. Overexploitation of fuelwood for mava-making, damaging to KWLS forest integrity and functioning for yield low economic benefits, is one such example for which alternative resources may be identified to support livelihoods more sustainably.

Evaluation of services can also help identify potential novel markets, for example exploration of payment for ecosystem services (PES) schemes as recently developed in Sanjay Gandhi National Park (Mumbai), and other funding arrangements to justify and encourage novel investment and more equitably share the benefits and costs of conservation (Everard *et al.*, 2020). Enforcement of pre-existing legal prohibitions on resource extractions could better protect and support the regeneration of ecosystem quality and some services, such as potential ecotourism enhancement or water-vectored ecosystem services enjoyed in downstream catchments, though this may disadvantage local communities currently illegally extracting biomass and other assets from within the KWLS. Conservation easements can also provide a means to favour preferential management in both protected and non-protected areas (Benez-Secanho & Dwivedi, 2020). A compromise may include sustainably produced crops or timber from the PA, and cultural services such as recreation, tourism, research opportunities and maintaining cultural identity, including recognizing the importance of spill-over services beyond the PA (Hummel *et al.*, 2019). Of particular societal importance are the life-support functions of ecosystems, often overlooked historically yet of increasing importance in an urbanising world of growing human numbers challenged by a changing climate (Ferreira *et al.*, 2019).

Expansion of range for the growing tiger population is framing consideration of increasing protecting of the KWLS ecosystem. If this primary driver is addressed as an 'anchor service' (*sensu* Everard, 2014) including co-benefits for other top predators such as caracal (*Caracal caracal*) (Khandal *et al.*, 2020), optimisation of societal values across a range of ecosystem services achieved through a 'systemic solutions' approach (Everard & McInnes, 2013) can better resolve conservation goals with the generation of multiple, closely linked ecosystem service co-benefits. This strategy is economically rational, contributing to the wellbeing and prosperity of the large human population dependent on enhanced services deriving from protection and recovery of the KWLS ecosystem, whilst transparently acknowledging potential trade-offs.

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## Conclusions

Recognition and valuation of a broad range of ecosystem services, often overlooked historically, in addition to primary wildlife conservation goals is of increasing importance for PA management and appreciation.

Ecosystem service assessment represents a significant mechanism for recognition and valuation of a range of qualitatively differing ecosystem services, including potential conflicts as well as synergies between beneficiary groups resulting from management decisions and actions.

Novel policy mechanisms, such as exploration of payment for ecosystem services (PES) schemes, can justify and encourage investment and more equitably share the benefits and costs of conservation.

Greater protection of the KWLS ecosystem can benefit tigers and other wildlife with co-beneficial ecosystem service outcomes, though acknowledging disbenefits for communities currently directly and illegally exploiting forest resources.

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