

EVALUATION 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 (*Panthera tigris*) 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 aims to reveal the many societal values generated within KWLS by assessing ecosystem service flows and values on a systemic basis, supported by substantial primary fieldwork. 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 included: (1) benefit flows of INR 84.47 billion year⁻¹; (2) natural capital stock of 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 re-established 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: Ranthambhore; tiger; livelihoods; Rajasthan; VALUE+

The forest is a peculiar organism of unlimited kindness and benevolence that makes no demands for its sustenance and extends generously the products of its life activity; it affords protection to all beings, offering shade even to the axe-man who destroys it.

Gautama Buddha

INTRODUCTION

Numbers of Tigers (*Panthera tigris*) in Ranthambhore Tiger Reserve (RTR), Rajasthan state (India), have recovered in recent decades. (RTR comprises Ranthambhore National Park as well as the adjacent Sawai Mansingh and Kailadevi Wildlife Sanctuaries.) This has resulted in animals formerly occupying the core, highly protected Ranthambhore National Park (RNP) 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 led to the complete loss of Tigers from KWLS by 2000 (Singh & Reddy, 2016). Increasing human and livestock encroachment intensified degradation, social unrest and conflict between local villagers and migratory grazers. The reappearance of Tigers in KWLS from 2011, initially intermittent but later including sightings of a tigress with two cubs in 2018 (personal communication, Forest Department staff) highlights the importance of improving 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 of the national area, yet constitute the 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. Conservation of ecosystem services is increasingly incorporated into protected area goals, potentially improving co-management for biodiversity and ecosystem services (Floris et al., 2020; Li et al., 2020). A broader 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 protected areas (Wei et al., 2020) and stringent measures in many protected areas can generate inequalities of access to cultural services (Martinez-Harms et al., 2018). Refocusing management of protected areas 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 six of India’s Tiger Reserves (Corbett, Kanha, Kaziranga, Periyar, Ranthambhore and the Sundarbans) using the VALUE+ approach concluded that they provided US\$769–2,923 ha⁻¹ year⁻¹ of quantifiable socio-economic benefits (Verma et al., 2015, 2017). Khanna et al. (2015) and Bhagabati et al. (2014) presented a strong economic case for the conservation of KWLS forest, and Everard et al. (2017) recommended protection of corridor habitats between RNP and KWLS to improve wildlife movement and alleviate wildlife–human conflict. Average monetised ecosystem services benefits of INR 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 the consequences for overall value, including disbenefits to local stakeholders who may require compensation.

Ecosystem service evaluation is becoming an established method 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 unquantifiable using

financial values (Schmidt et al., 2016). Innovative methods are necessary to address knowledge gaps and to account for less tangible benefits from 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 in decision-making spanning intrinsic, instrumental and relational values, and addressing power relations among different perspectives. However, this is not without practical difficulties. For example, Ye et al. (2020) proposed an ecosystem intrinsic value (EIV) metric based on such 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 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, 2017), deriving conservative estimates for 21 ecosystem services. ‘VALUE’ denotes economic 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 RNP 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 the recovery of keystone predators (Gregg 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 km² (Pathak, 2009), 401.63 km² of which is defined as critical Tiger habitat of the

RTR (Forest Department, Rajasthan, 2015). Climate is semi-arid with average annual rainfall of 750–800 mm, about 90 per cent falling during the July–September monsoon season, with temperatures of 2 to 15°C in winter (November–February) and exceeding 47°C in summer with frequent droughts (Forest Department, Rajasthan, 2015). KWLS forms the northern boundary of the Ranthambore National Park (RNP) (Figure 1), separated by the Chambal River corridor that forms an important route for animal movements between the protected areas (Thorat & Gurjjer, 2010; Forest Department, Rajasthan, 2015).

The KWLS terrain is characterised by the 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 km² is Dhonk forest, 98.83 km² is mixed forest in the khoh, 2.42 km² is encroached human habitation and 34.24 km² is farmland. These forests protect the watershed of the Chambal and Banas Rivers (Forest Department, Rajasthan, 2015; Thorat & Gurjjer, 2010).

Vegetative cover elsewhere in KWLS is relatively sparse. Dhonk (*Anogeissus pendula*) is the dominant tree, constituting 80 per cent of 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



Deep gorges (khoh) host rich, moist forests © Mark Everard



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

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 KWLS.

METHODS

Evaluation methods, both monetary and non-monetary, must be relevant to the 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 the use of VALUE+ applied to India's Tiger Reserves as a neoliberal attempt to hide 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 Online Material.

Table 1. Summary of methods for assessing ecosystem services

Methods use to assess specific ecosystem services
<p><i>Fodder-related ecosystem services</i> are important to villagers within and adjacent to KWLS as livestock plays an important role in India's economy:</p> <p>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).</p> <p>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.</p>
<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> <p>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).</p> <p>Wood extraction: Though also technically illegal, wood extraction remains a primary fuel source for people living in and adjacent to KWLS. Fuelwood and other biomass (dung cake, agriculture residues, etc.) consumption by villages was quantified in 15% of randomly selected villages.</p>
<p><i>Carbon stock and sequestration ecosystem services</i>, of value to the global community through climate stabilisation:</p> <p>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).</p> <p>Annual grassland carbon sequestration: Grassland productivity assessment was converted to carbon content after Penman <i>et al.</i> (2003).</p>
<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> <p>Sedimentation: Assessed by valuation of downstream sedimentation avoidance, based on offset costs of dredging after Verma <i>et al.</i> (2015).</p> <p>Nutrient retention: Assessed using commercial fertilizer replacement costs.</p>
<p><i>Water-related ecosystem services</i>, beneficial to surface and groundwater users adjacent to the KWLS perimeter including supporting fish production:</p> <p>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).</p> <p>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.</p> <p>Groundwater recharge: KWLS serves as a groundwater catchment vital for adjacent communities, assessed quantitatively and economically based on land cover categories.</p> <p>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.</p>
<p><i>Tourism ecosystem services</i>, beneficial to tourist but with income realized by tourism operators and local involved communities:</p> <p>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).</p>
<p><i>Qualitatively described ecosystem services</i> are not inherently monetizable. The relative significance of intrinsic values as well as adjacent pollination and non-timber forest product (NTFP) beneficiaries was informed by literature review, discussions with local and international experts, and community consultations:</p> <p><i>Pollination services: Significant for agriculture and food security, but lacking quantitative methods relevant to KWLS.</i></p> <p><i>Genetic resources: Significant but not inherently quantifiable.</i></p> <p><i>NTFPs: Diversity and approximate scale extracted from KWLS were assessed based on community surveys.</i></p>
<p><i>Miscellaneous ecosystem services</i>, related generally to intrinsic values as well as local and adjacent beneficiaries of disease and pollination services</p> <p>Inherent values for KWLS 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 <i>et al.</i> (2015).</p>

RESULTS

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

Fodder-related ecosystem services

The socio-economic survey revealed seasonally variable grazing, yielding direct benefits to livestock owners (Supplementary Online Material, S1). 80 per cent of villager cattle spend 10 months and feral cattle typically spend 8 months within KWLS, and domestic cattle from nearby villages are brought in from July to October by kirkadis (cattle camps). Total Adult Cattle Unit (ACU) grazing in KWLS was calculated as 50,288.4 requiring (at 6.5 kg per day per ACU) 76,993.72 tonnes year⁻¹ fodder.

- Dhonk leaf biomass production was estimated at 9,619.81 tonnes, with total value estimated as INR 19.23 million year⁻¹. Owing to the slow growth of the forest – unlike that of grassland, straw, small-scale cropping and weed harvesting – there is a need to control overharvesting to protect other ecosystem services flowing from forested plateaus.
- Total standing dry above-ground biomass of grassland was calculated as 1.94 tonnes ha⁻¹, a low grassland productivity attributed to heavy grazing and subsequent loss of soil and nutrients. Available grassland fodder dry weight was calculated as 2.480 ha⁻¹ year⁻¹, with a total economic value (multiplying by grassland area and INR 4 kg⁻¹) of INR 343.19 million. Grazing pressure is 50 per cent higher than the recommended stocking limit of 1 ACU per hectare (Planning Commission of India, 2011), threatening ecosystem structure, functioning and conservation (Eldridge et al., 2016).
- Straw production was estimated at 11,219.09 tonnes year⁻¹ broken down between wheat, paddy and bajra, with a total annual economic value of INR 44.87 million.
- Production of oilcake from mustard (1,056 kg ha⁻¹) and sesame (326 kg ha⁻¹) was calculated as worth INR 6.91 million year⁻¹.
- Green weed production (0.1 tonnes ha⁻¹ year⁻¹) was multiplied by field area in KWLS, deriving a quantity of 284.94 tonnes year⁻¹. Multiplying by a local market price of INR 2,000 tonne⁻¹ yields an economic value of INR 0.56 million year⁻¹.
- 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⁻² year⁻¹) to derive total production of 108 tonnes year⁻¹. Based

on local market price of INR 2,400 tonne⁻¹, economic value is INR 0.26 million year⁻¹.

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

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 m³ with a value of INR 34 billion (Supplementary Online 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 are extracted for the construction of houses, barns and cattle sheds, fencing, making agricultural and household tools, 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⁻¹, with the wood volume of 10 poles calculated as 0.159 m³. Multiplying by the 2,663.75 families within KWLS determined by household surveys, approximately 423.53 m³ of small timber worth INR 12.01 million is extracted annually.

Field assessment found fuelwood consumption of 7,617.44 tonnes year⁻¹, worth INR 38.08 million, representing an avoided cost for procuring other fuel sources. Socio-economic surveys found that 55 per cent of fuelwood is used for mava-making by communities heavily dependent on cattle but lacking ready markets necessitating conversion to mava and ghee. One kilogram of mava is produced from 4 kg milk, requiring 10 kg wood. An average 2 kg mava day⁻¹ is produced by every family, aggregating to 1,710 kg day⁻¹ (250 days production annually reflecting seasonal variability). Mava is sold at INR 30 l⁻¹, 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 within KWLS), cow dung cake (only a small level of consumption was found by survey

of 0.65 kg day⁻¹ or 237.25 kg year⁻¹), and LPG cylinders (low uptake due to lack of refilling stations and cultural beliefs including taste of food).

Carbon stock and sequestration ecosystem services

Carbon stock and sequestration was quantified in different forest types and grassland in KWLS, represented in monetary values in terms of global socio-economic 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⁻¹. An area of 14,828 ha of Dhonk forest therefore stores 0.62 million tonnes carbon, worth INR 493.93 million. Consequently, sequestration potential is 8,748.52 tonnes carbon year⁻¹, with estimated value of INR 6.86 million year⁻¹.

Total carbon in ravine forest was 26.22 t C ha⁻¹, 31.16 per cent higher than Dhonk forest. A total of 3,700 ha of ravine scrubland therefore stores 0.25 million tonnes carbon, worth INR 200.76 million. Sequestration potential is therefore 4,612.8 tonnes of carbon year⁻¹ with estimated value of INR 3.617311632 million year⁻¹ 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 diverse wildlife habitat, serve as wildlife corridors especially outside protected areas (Khandal & Khandal, 2013) and this study highlights their importance for productivity.

Total carbon in khoh forest was 78.19 t C ha⁻¹, exceeding both Dhonk forest and ravines. Therefore, 9,883 ha of khoh forest stores 1.19 million tonnes carbon, worth INR 936.14 million. Consequently, sequestration potential is 16,899.93 tonnes of carbon year⁻¹, with estimated value of INR 13.25 million year⁻¹ based on a social cost of carbon of US\$11 tonne⁻¹ at 4 per cent discount rate for 2015 (EPA, 2016).

Carbon stock in seasonal grassland was calculated as 1.19 million tonnes, valued at INR 939.77 million. Seasonal grasslands in the KWLS sequester 80.61 tonnes of carbon⁻¹, worth INR 63.21 million year⁻¹. The KWLS seasonal grassland is heavily modified by intensive grazing and tree cutting; habitat protection would increase carbon sequestration and other ecosystem service flows.

Total carbon stock in the KWLS is estimated at 2.08 million tonnes with an economic value of INR

2,570.629 million. Total estimated annual carbon sequestration is estimated at 0.11 million tonnes year⁻¹, with an economic value of INR 86.94 million year⁻¹. 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.

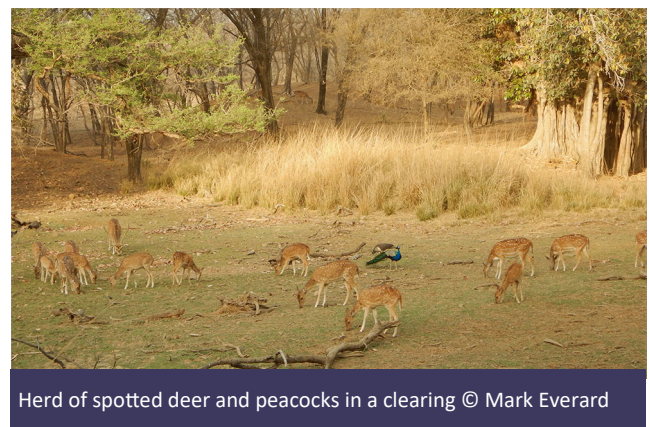
Soil- and water-related ecosystem services

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

- Soil retention, which was not directly valued, but informs the economic valuation of avoided off-site costs from sedimentation and nutrient loss.
- Sedimentation avoidance from the KWLS was calculated as 80,621.7 m³ year⁻¹ with a total economic value of INR 4.701 million year⁻¹.
- 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 for KWLS of INR 85.92 million year⁻¹ (INR 5.95, 0.43 and 79.54 million 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 the cumulative surface area of a small lake known as Pangara (3.26 km²) and a small additional artificial reservoir retained by a masonry dam located at Kalyanpura (2.1 km²). This total volume was multiplied by canal irrigation water costs yielded a value of INR 0.16 million. If consumed within a year, this also represents an annual benefit value.



Herd of spotted deer and peacocks in a clearing © Mark Everard

- Water volume in reservoirs outside KWLS but whose waters originate in the park were also valued. These include Needhar dam, the water of which is sourced completely from the KWLS, and a 50 per cent contribution to Kalisil Reservoir, Mamchari Dam and Atewa Dam. Irrigation water from these reservoirs yielded a total estimated economic value from KWLS of INR 0.61 million year⁻¹.
- Groundwater recharge within KWLS was estimated at 40.17 million m³ year⁻¹, valued at INR 823.16 million year⁻¹.
- Fish productivity in dependent dams was calculated as 34,960 kg year⁻¹, worth INR 0.34 million year⁻¹.

Soil- and water-related ecosystem services provided by KWLS total INR 914.86 million year⁻¹.

Tourism ecosystem services

Focus group discussions revealed approximately 52,980 tourist visits to the five selected temples year⁻¹, most tourists coming from nearby villages and small towns though the Kedar Baba temple is visited by more distant pilgrims (Supplementary Online Material, S5). Aggregated travel costs derived a value of INR 6,894,000 year⁻¹, 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.

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 Online Material, S6).

2,551.07 ha in the KWLS were found by survey to be under cultivation in the kharif season, with 1,749 ha cropped in the rabi season. Cereal grains dominate and are 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. Socio-economic 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.

Miscellaneous ecosystem services

Table 2 records values for other miscellaneous services provided by KWLS transferred from the Verma et al. (2015) study of the adjacent Ranthambhore division of RNP, 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

Table 2. Values for miscellaneous ecosystem services provided by KWLS

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

regulation services, and breakdown of waste products – have a cumulative value of INR 6,979.81 million year⁻¹ (Supplementary Online Material, S7).

DISCUSSION

The assessment of 21 ecosystem services illustrates the systemically interconnected, multiple values provided by KWLS. These include service flows of INR 12.55 million km⁻² year⁻¹; 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 are tangible for local users of resources whilst others demonstrate more wide-scale indirect benefits to broader constituencies beyond, and sometimes distant from, the park boundary.

Demonstration of this multiplicity and the scale of values are significant for communication of the wider importance of KWLS, consistent with the wider uptake of ecosystem service conservation within protected area goals (Floris et al., 2020; Li et al., 2020). This

evaluation highlights the 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 protected area.

The 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

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 ⁻¹ , or INR millions for stock values)	RTR, from IIFM study (INR millions yr ⁻¹ , or INR millions for stock values)
Study area	672.8 km²	780 km²
Flow services		
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
Total flow services	INR 84.41 billion yr⁻¹	INR 94.88 billion yr⁻¹
Stock services		
Carbon stock	2.570	5.010
Timber stock	34.1	44.190 (after adjustment of the error)
Total stock services	INR 36.6 billion	INR 49.2 billion



Tiger in cover in Ranthambhore National Park © Mark Everard

ecosystem service benefits across a spectrum of geographical scales whilst also reducing other services.

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 park 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, which is damaging KWLS forest integrity and functioning while yielding 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 an 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 equitable sharing of the benefits and costs of conservation (Everard et al., 2020). Enforcement of pre-existing legal prohibitions on resource extraction 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 protected area, and cultural services such as recreation, tourism, research opportunities and maintaining cultural identity, including recognising the importance of spill-over services beyond the protected area (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 protection for 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 integrate nature conservation goals with generation of multiple, closely linked ecosystem service co-benefits. This strategy is economically rational, contributing to the well-being and prosperity of the large human population dependent on enhanced services deriving from the protection and recovery of the KWLS ecosystem, whilst transparently acknowledging potential trade-offs.

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 protected area management and appreciation.

Ecosystem services assessment represents a significant mechanism for the 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.

SUPPLEMENTARY ONLINE MATERIAL

Supplementary details of methods and results

S1 Fodder-related ecosystem services

S2 Timber and fuelwood-related ecosystem services

S3 Economic value of carbon stock and sequestration

S4 Economic value of soil- and water-related ecosystem services

S5 Economic value of tourism

S6 Qualitatively described ecosystem services

S7 Miscellaneous ecosystem services

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RESUMEN

El Santuario de Vida Silvestre de Kailadevi (KWLS, por sus siglas en inglés), en Rajastán (India), perdió su población de tigres (*Panthera tigris*) en 2000, aunque desde 2019 los tigres han migrado desde el adyacente Parque Nacional de Ranthambhore (RNP, por sus siglas en inglés). Si bien están protegidos, los bosques del KWLS han sido diezmados por la explotación de las comunidades humanas residentes y migratorias. Este estudio pretende revelar los numerosos valores sociales generados en el KWLS mediante la evaluación de los flujos y valores de los servicios de los ecosistemas sobre una base sistémica, con el apoyo de un importante trabajo de campo primario. Un enfoque basado en los valores utilizó entrevistas locales, trabajo de campo primario y literatura para determinar la provisión de servicios de los ecosistemas por parte del KWLS y –en la medida de lo posible– con representación monetaria. Los valores conservadores estimados para 21 servicios de los ecosistemas incluyeron (1) flujos de beneficios del orden de 84.470 millones de INR al año-1; (2) reservas de capital natural de 367.300 millones de INR; y (3) servicios de los ecosistemas no cuantificados. Si bien los valores monetarios son representaciones puramente ilustrativas basadas en gran medida en los mercados sustitutos, indican, no obstante, la gama y escala de los beneficios sociales poco apreciados. La comparación entre el KWLS y el RNP ilustra las diferencias en la prestación de servicios entre los ecosistemas menos protegidos y los más protegidos, incluyendo el potencial para mejorar servicios como el ecoturismo y los espacios para el restablecimiento de las poblaciones de tigres y otras especies silvestres, pero también las posibles desventajas para quienes actualmente extraen recursos del KWLS, que podrían verse desplazados o que podrían requerir una indemnización.

RÉSUMÉ

Kailadevi Wildlife Sanctuary (KWLS), au Rajasthan (Inde), a perdu sa population de Tigres (*Panthera tigris*) en 2000, mais depuis 2019 des Tigres en provenance du parc national de Ranthambhore (RNP) adjacent ont commencé à se répandre au KWLS. Bien que protégées, les forêts de KWLS ont été ravagées par l'exploitation des communautés humaines résidentes et migratrices. Cette étude vise à révéler les nombreuses valeurs sociétales générées au sein du KWLS en évaluant les flux et les valeurs des services écosystémiques sur une base systémique, appuyée par un important travail de terrain primaire. Une approche VALEUR+ a permis de prendre en compte des entretiens locaux, des travaux de terrain primaires et de la documentation afin de déterminer l'apport des services écosystémiques fourni par KWLS, autant que possible avec une représentation monétaire. Les valeurs conservatrices estimées pour 21 services écosystémiques comprenaient (1) des flux de bénéfices de 84,47 milliards INR par an-1; (2) un capital naturel de 367,3 milliards INR; et (3) des services écosystémiques non quantifiés. Les valeurs monétaires sont purement indicatives et basées en grande partie sur des marchés de substitution, mais elles indiquent néanmoins l'éventail et la portée d'avantages sociétaux encore difficiles à chiffrer. La comparaison du KWLS avec la RNP illustre les disparités entre les services apportés par les écosystèmes les moins protégés et les écosystèmes hautement protégés, notamment leur potentiel pour l'amélioration des services tels que l'écotourisme et l'établissement d'un environnement propice à la population de tigres rétablis et d'autres espèces sauvages, ainsi que des inconvénients potentiels pour ceux qui extraient des ressources de KWLS et qui pourraient être déplacés ou requérir une compensation.