

The first rapid forest inventory and resource use assessment of Dashtijum Nature Reserve, Tajikistan: a mixed methods approach

FRED PILKINGTON, MINERVA SINGH, VICKY WILKINS and COLIN CLUBBE

Abstract There is critical need for more information on the status of forests in Central Asia, to inform conservation management. Here we assess the status and use of the globally important, threatened walnut–fruit forests of Dashtijum Nature Reserve, Tajikistan. We use a mixed methods approach combining a semi-structured interview based socio-economic survey with statistical analysis. Thirty-three tree species were recorded, with Rosaceae the most common family. The mean basal area of the forest was 20.8 m² per ha and most tree species exhibited stable population structures. Resource use was prevalent throughout the community; most households harvested at least one fruit or nut species (78%), firewood (88%) and grazed livestock (85%). Most respondents noted declines in availability of fruits, nuts and firewood and reported a decrease in the overall area and quality of grazing. Statistical analysis and machine learning identified that distance to nearest settlement significantly affected forest total basal area, tree species richness and the Shannon index, a metric of diversity sensitive to rare species. Our results suggest that conservation management by the government and NGOs is partly effective but there is a need for increased enforcement of grazing restrictions, to prevent further forest degradation.

Keywords Anthropogenic disturbance, crop wild relative, grazing, natural resource management, non-timber forest product, NTFP, Tajikistan, walnut–fruit forest

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Introduction

Tajikistan is the poorest country in Central Asia (Zhupankhan et al., 2017), with one of the highest levels of livelihood and food insecurity risks (Sutton et al., 2009). Almost half of Tajikistan's population live rurally and there is intense pressure on natural resources (Ajwad et al., 2014). During the 20th Century, Tajikistan's population increased six-fold (Safarov, 2003) resulting in prolonged unsustainable exploitation of its limited natural resources (Wolfgramm et al., 2011) and widespread land degradation (Lerman, 2011). To prevent further environmental degradation and help alleviate poverty, management options, including expansion of land holdings and the reforestation of key areas, have been proposed (Lerman, 2012). With effective management, ecosystem services provided by forests, such as carbon sequestration and biodiversity conservation, can be substantially enhanced (Safarov et al., 2014).

Sustainable forest management encompasses the provision of all forest ecosystem goods and services in perpetuity, including the supply of non-timber forest products (NTFPs; Lindenmayer et al., 2000). Tajikistan's forests have experienced almost a century of overexploitation because of poor management (Maselli & Rahim, 2012). Forest cover declined from 25% in the 1920s to < 3% in 2007, making Tajikistan the most deforested country in Central Asia (FAO, 2007). Efforts to encourage land restoration have been limited by poor decision making, combined with chronic overgrazing and land tenure issues (FAO, 2010; Halimova, 2012). A key challenge facing the government's Forestry Department is the lack of reliable data on forest distribution and composition (Mislimeshova et al., 2016).

Five mountain ranges converge in Tajikistan, creating a global biodiversity hotspot of which the forest community and its associated tree species are essential elements (Squires & Safarov, 2013; Orozumbekov et al., 2014). The walnut–fruit forests of Central Asia are of special scientific interest as they have been identified as the source of numerous domesticated tree species (Beer et al., 2008). Tajikistan's forest community contains 10 fruit and nut species, five of which are categorized as threatened on the IUCN Red List (Squires & Safarov, 2013; Supplementary Table 1). These ancestral species are harvested for fruits, nuts and firewood during May–November and play a vital role in the region's culture and livelihood security (FAO, 2010). Tajikistan's forests, and the communities that rely on them, are the focus of monitoring research, protection efforts to facilitate natural

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regeneration, reforestation of native species, and capacity building combined with outreach with local Forestry Management Units (Darwin Initiative, 2017; FFI, 2018).

This study is the first forest inventory conducted in Dashtijum Nature Reserve and only the second conducted in Tajikistan since 1943 (Nowak et al., 2011). Our aims were to evaluate the magnitude and spatio-temporal pattern of anthropogenic disturbance and forest resource use within the Reserve and to identify drivers of biotic diversity using regression and machine learning methods.

Study area

We conducted our research during May–July 2017 in the 350 km² Dashtijum Nature Reserve, Khatlon province, Tajikistan (Fig. 1). The region is characterized by a temperate climate with a mean annual temperature of 11 °C, total annual precipitation of 500–1,500 mm and relic broadleaf montane deciduous forests (Safarov, 2003). The c. 150 km² study area has a mean altitude of 1,445 ± SD 265 m (range 1,014–2,307 m). There is a mixed economy in the Reserve, with NTFPs harvested both for subsistence and for cash income (World Bank, 2004). Animal husbandry is equally important, with most of the population owning a combination of cows, equids and sheep (Squires & Safarov, 2013).

Methods

Surveys

We identified areas for forest surveys through discussions with Forestry Department employees, with a bias towards larger forested areas (Gordon et al., 2004). We used 0.25 ha plots to ensure adequate representativeness as the heterogeneity and mean patch size of the forest was unknown (Kenkel & Podani, 1991). To maximize proportionality between the number of samples and the forest size (Southwood & Henderson, 2015), up to three plots were surveyed within each forest area, with a minimum of 300 m between plots. Within each survey area, a random walk technique was employed to select the north-west corner of each plot (Dytham, 2015).

A tree was defined as having ≥ 30 cm circumference at breast height and ≥ 1.5 m height (breast height = 1.3 m from ground level; Newton, 2007). We measured the circumference at breast height of every tree within each of 40 plots and converted to diameter (*d*), which was used to calculate basal area (*g*) using

$$g(\text{m}^2) = \frac{\pi d^2}{(4 \times 10,000)} \quad (1)$$

from Husch et al. (2003).

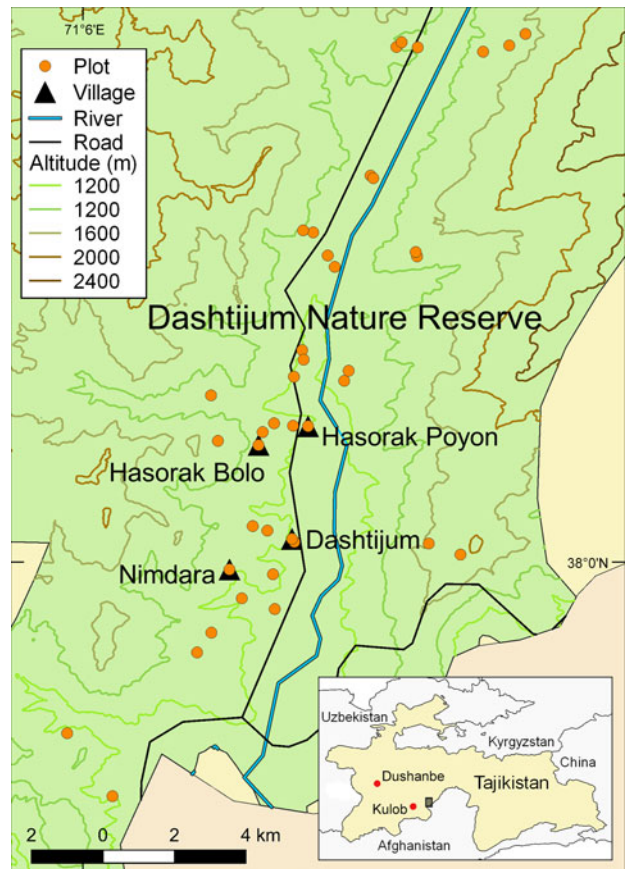


FIG. 1 Location of the 40 survey plots, and the four villages where people were interviewed, in Dashtijum Nature Reserve, Tajikistan.

We recorded presence of hay harvesting along with a visual estimate of canopy cover using a 5-point scale (1: very open; 5: very dense; Korhonen et al., 2006). Additionally, we recorded the livestock disturbance indicators proposed by Reimoser et al. (1999) of browse line and trampling incidence using a 4-point scale (high, medium, low, absent). Livestock dung, sapling and seedling density were measured within a 5 × 5 m subplot located randomly within each plot. Species-specific dung counts were combined into a measure of potential threat using the grazing conversion metrics 0.6 for cattle, 0.58 for equids and 0.1 for sheep (Chilonda & Otte, 2006). We recorded plot location and altitude using a GPS and measured slope angle using a clinometer. Distance to nearest settlement, known to influence anthropogenic disturbance positively and biodiversity negatively (Ahrends et al., 2010), was measured post-hoc using the *Open Layers* plugin on QGIS 2.18.2 (QGIS Development Team, 2020).

Stakeholder interviews

We conducted semi-structured interviews to gain insight into the spatio-temporal patterns of forest resource use, and the economic and cultural importance of these forests.

Forest resource use encompassed NTFP harvesting, timber extraction and forest grazing practices. The interview (Supplementary Material 1) was based primarily on a set of questions following Cantarello et al. (2014), refined through discussion with Forestry Department employees and Fauna & Flora International staff. The interview was subsequently translated into Tajik, piloted with three members of the local populace, and edited to ensure its contextual accuracy and retention of intended meaning. Resource use was shared between men and women, and therefore we aimed for a 50:50 split between male and female respondents. For comprehensive coverage of the four largest villages within the Reserve, we divided the total number of households ($n = 280$) by the desired number of interviews ($n = 40$) and therefore visited every 7th household. Interviews were with one representative from each household and only took place with free, prior and informed consent.

Data analysis and modelling

The Shannon (Shannon & Weaver, 1949) and Simpson (Simpson, 1949) indices both combine two properties of diversity: richness (the number of species), and evenness (the proportion of each species). We used Shannon's index as it is more sensitive to changes in the abundance of rare species (Peet, 1974), of which the survey area has a considerable number, whereas Simpson's index is more responsive to dominant species (Nagendra, 2002). To complement Shannon's index, species richness (McIntosh, 1967) was also used in the modelling. A species accumulation curve was analysed visually to judge sampling adequacy. Stem diameters, grouped into 5 cm classes, were analysed visually to infer species-specific age distributions. The Importance Value Index of each tree species was calculated as the mean of relative frequency, relative density and relative dominance, all expressed as percentages (Curtis & McIntosh, 1950). Relative frequency was calculated by dividing the frequency (the number of quadrats with the species present) by the sum of all species frequencies. Relative density calculations followed the same process, using the number of trees per ha. Relative dominance was calculated using total basal area divided by the sum of the basal area of all species.

We used a stepwise multiple linear regression to identify the most significant variables (Supplementary Table 2) influencing the variation in total basal area and Shannon index (Badreldin & Sanchez-Azofeifa, 2015). A generalized linear model was used for modelling species richness because the count data exhibited a Poisson distribution (Lovett et al., 2006; Fletcher & Fortin, 2018).

Random Forest (Breiman, 2001), a machine learning algorithm, was used to quantify the influence of each predictor variable on the three response variables (species richness, Shannon index and total basal area). Marginal response curves (derived using the Random Forest algorithm) were

used to identify the impact of individual predictor variables (such as those relating to disturbance) on the four response variables. The influence of qualitative predictor variables on the response variables was identified and quantified using Kruskal-Wallis tests (Singh et al., 2015).

Results

Survey data

In total, we recorded 1,380 trees representing 33 species (Table 1). The species with the highest Importance Value Index was *Prunus sogdiana* (21.6%) followed by *Morus alba* (17%) and *Juglans regia* (10.1%; Table 1); 48% of relative dominance was explained by *P. sogdiana* and *M. alba* (Supplementary Table 3). The mean basal area of the forest was $20.8 \pm \text{SD } 1.3 \text{ m}^2$ per ha and the mean density of saplings and seedlings were $1,320 \pm \text{SD } 101$ per ha and $4,397 \pm \text{SD } 248$ per ha, respectively. Of the 17 most numerous species, accounting for 93% of individuals, 13 species had type I and four species had type II stem diameter distributions (see Supplementary Fig. 1 for the 10 most utilized species). The species accumulation curve (Supplementary Fig. 2) almost reached an asymptote, indicating that most species were found with the sampling effort employed.

We interviewed an equal number of men and women. All interviewees were engaged in at least one type of resource extraction. The mean number of species gathered was $4 \pm \text{SD } 2.68$ (range 0–8) and 78% of households collected at least one species of fruit or nut from the forests; *P. sogdiana* (73%), *Malus sieversii* (68%) and *Crataegus pontica* (65%) were the most commonly harvested species (Fig. 2).

Most households reported an increase in the travel time to the fruit and nut collection sites (55%) and a decrease in the total amount of fruit and nuts collected (65%) compared with 5 years previously (Fig. 3). All participants noted that most tree species were either very important or important for the health of the forest ecosystem.

For firewood, 88% of households harvested it and 12% purchased it locally. Of those harvesting firewood, all commented that it was economically important or very important and 78% stated it was for subsistence. The majority of households collected firewood every day from any tree species (48%) or from two or more species (43%); 92% of sample plots had branches cut and 47% of all trees surveyed had branches cut for firewood harvesting. Households reported a decrease in the total amount (83%; Fig. 3) and an increase in the travel time to arrive at harvesting sites (83%; Fig. 3) over the previous 5 years. All respondents noted an increase in the effectiveness of management by the Forestry Department and widespread community involvement in enforcing the ban on harvesting of live branches. Most households (98%) reported no collection of timber and those that did stated they did so rarely and for subsistence

TABLE 1 Stand structure of the forests of Dashtijum Nature Reserve, with mean tree basal area, tree density and Importance Value Index (IVI; see main text for details of calculation) of all tree species found.

Species	Family	Mean basal area \pm SD (dm ² per ha)	Tree density per ha	IVI (%)
<i>Pistacia vera</i> L.	Anacardiaceae	160 \pm 9.2	2.8	3.9
<i>Celtis caucasica</i> Hohen. ex Planch.	Cannabaceae	57 \pm 2.6	3.3	2.6
<i>Lonicera nummulariifolia</i> Jaub. & Spach	Caprifoliaceae	142 \pm 4.1	5.1	5.1
<i>Juniperus seravshanica</i> Kom.	Cupressaceae	1 \pm 0.4	0.2	0.4
<i>Elaeagnus angustifolia</i> L.	Elaeagnaceae	2 \pm 0.7	0.4	0.8
<i>Calophaca grandiflora</i> Regel	Fabaceae	5 \pm 0.5	0.8	0.7
<i>Juglans regia</i> L.	Juglandaceae	193 \pm 1.4	16.2	10.1
<i>Cercis griffithii</i> Boiss.	Leguminosae	110 \pm 6.1	3.1	2.8
<i>Punica granatum</i> L.	Lythraceae	12 \pm 0.5	2.8	1.2
<i>Morus alba</i> L.	Moraceae	622 \pm 2.5	20.1	17.0
<i>Ziziphus jujuba</i> Mill.	Rhamnaceae	6 \pm 3.8	2.6	1.0
<i>Amygdalus bucharica</i> Korsh.	Rosaceae	6 \pm 0.3	1.9	1.2
<i>Armeniaca vulgaris</i> L.	Rosaceae	18 \pm 1.2	0.8	1.4
<i>Cerasus avium</i> L.	Rosaceae	2 \pm 0.8	0.4	0.6
<i>Cerasus padus</i> (L.) DC.	Rosaceae	6 \pm 0.3	2.3	1.6
<i>Cerasus tomentosa</i> Thunb.	Rosaceae	0.3 \pm 0.0	0.1	0.2
<i>Cotoneaster nummularius</i> Fisch. & C.A. Mey	Rosaceae	35 \pm 5.2	0.8	1.2
<i>Crataegus pontica</i> K. Koch	Rosaceae	26 \pm 0.5	8.2	5.5
<i>Crataegus turkestanica</i> A. Pojark.	Rosaceae	4 \pm 0.4	0.8	0.7
<i>Cydonia oblonga</i> Mill.	Rosaceae	45 \pm 18.1	0.5	1.5
<i>Exochorda albertii</i> Regel.	Rosaceae	6 \pm 0.8	0.6	1.0
<i>Malus sieversii</i> M. Roem.	Rosaceae	102 \pm 1.7	10.5	7.3
<i>Prunus mahaleb</i> L.	Rosaceae	35 \pm 6.3	1.1	1.3
<i>Prunus sogdiana</i> Vass.	Rosaceae	381 \pm 2.6	43.6	21.6
<i>Pyrus korshinskyi</i> Litw.	Rosaceae	14 \pm 0.9	2.0	1.5
<i>Pyrus tadshikistanica</i> V.I. Zapr.	Rosaceae	19 \pm 0.2	1.2	1.8
<i>Rosa canina</i> L.	Rosaceae	4 \pm 2.0	0.2	0.4
<i>Populus caspica</i> (Bornm.)	Salicaceae	22 \pm 1.7	1.8	1.4
<i>Populus tadshikistanica</i> Kom.	Salicaceae	4 \pm 0.4	1.1	0.8
<i>Salix excelsa</i> S.G. Gmel.	Salicaceae	5 \pm 0.4	1.3	0.9
<i>Acer turkestanicum</i> Pax.	Sapindaceae	34 \pm 6.6	0.7	1.5
<i>Ulmus androssowii</i> Litw.	Ulmaceae	5 \pm 2.1	0.2	0.3
<i>Vitis vinifera</i> L.	Vitaceae	1 \pm 0.1	0.5	0.8
Total		2,081 \pm 127	138 \pm 8.3	100.0

purposes only. Most households (80%) noted an increase in the number of young trees (Fig. 3).

Most households (85%) owned livestock and 53% admitted to grazing their livestock in the forest, despite it being illegal. Evidence of disturbance by livestock was found in 90% of plots and few plots contained seedlings (28%) and saplings (15%). The total area and quality of grazing in the forest was reported to have decreased by 88% and 70%, respectively (Fig. 3), with a similar level of unanimity (75%) on the decreased quality of pastureland grazing.

Disturbance modelling

Forward selection with ordinary least squares regression identified the variables distance to nearest settlement and slope as the most parsimonious model that best explained

the variation in total basal area. The overall model was significant ($P < 0.05$) and explained a moderate amount of variance in the response variable ($R^2 = 0.20$, $F = 5.28$; Supplementary Table 4). A strong positive association was found between distance to settlements and total basal area ($r = 0.42$).

Random Forest identified and ranked the variables in terms of their importance in influencing the response variables. The variables low trampling and distance to the nearest settlement were key influencers of both species richness and Shannon's index (Table 2). An increase in distance to the nearest settlement resulted in an increase of all three response variables (Shannon's index, species richness and total basal area; Supplementary Fig. 3). For both measures of species diversity, the relationship with dung count was strongly negative, whereas for total basal area it was positive.

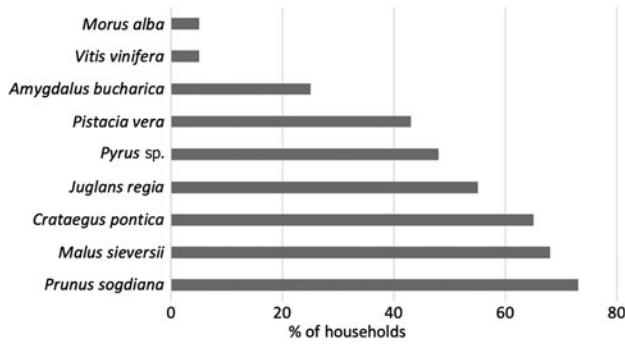


FIG. 2 Per cent of 40 households that harvested nine fruit or nut species from the forests in Dashtijum Nature Reserve (Fig. 1).

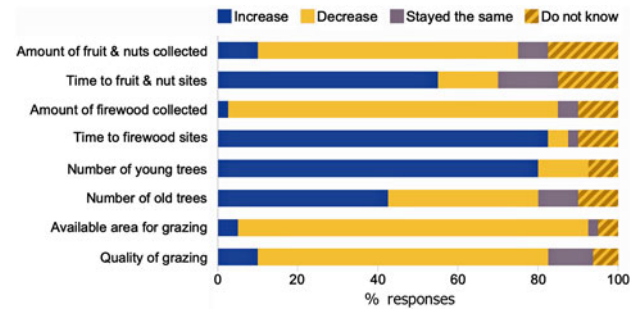


FIG. 3 Responses from 40 household interviews regarding compositional and resource changes within the forests of Dashtijum Nature Reserve (Fig. 1) over the previous 5 years.

TABLE 2 The importance (i.e. how important the predictor variables in a given model are in explaining the response variable), of various predictor variables in influencing species richness, the Shannon index and total basal area, computed using Random Forest models.

Species richness		Shannon index		Total basal area	
Predictor variable	Importance	Predictor variable	Importance	Predictor variable	Importance
Low trampling	100.00	Dung count	100.00	Altitude	100.00
Distance to nearest settlement	70.46	Low trampling	94.62	Dung count	86.36
Open canopy cover	60.37	Distance to nearest settlement	54.70	Medium canopy cover	52.85
Altitude	56.72	No browse line	49.93	Medium trampling	40.96
Low browse line	47.25	Dense canopy cover	43.00	Low browse line	31.71

Discussion

This study provides a rapid assessment of forest and resource use in Dashtijum Nature Reserve. The forest community comprised 33 species, similar to a comparable study in Kyrgyzstan (Cantarello et al., 2014), and the asymptotic nature of the species accumulation curve indicates an adequate survey effort, a satisfactory completeness of the inventory (Moreno & Halffter, 2000), and therefore a reliable estimation of species number.

Of the 17 species diameter distributions analysed, 11 had reverse J-curves which is indicative of balanced uneven age structures (Keyser & Loftis, 2013) and stable, self-maintaining populations (Peters, 1994) indicative of a healthy community. Two species, *C. pontica* and *P. sogdiana*, had steep reverse J-curves (i.e. type I) of diameter distribution, indicating an absence of large individuals and implying intense exploitative cutting in the 20th century (Wolfgramm et al., 2011). The stem diameter distribution curves of *M. alba* and *J. regia*, and to a lesser extent *M. sieversii* and *Amygdalus bucharica*, exhibited Type II size-class structures symptomatic of irregular seedling establishment (Peters, 1994). These four species are economically important and therefore overharvesting appears to be the most likely cause of these distribution shapes as they are specific to four species, two of which we found to be heavily harvested. However, other factors such as direct physical

damage to seedlings, a lack of pollinators or a lack of dispersal agents could also have influenced the shape of these size-class structures (Bond, 1994).

We observed a heavy reliance on firewood, consistent with previous research in the area (FAO, 2007). Respondents noted a decrease in the availability of firewood over the previous 5 years and an increase in travel time to harvesting locations, indicating this extraction may be unsustainable. However, the Forestry Department is implementing an intensive reforestation programme to combat 20th century exploitation, planting c. 15,000 native trees per year (M. Yorahmadov, pers. comm., 2017). The impact of this was noted by most households (Fig. 3). The widespread knowledge of fines, adherence to the law and enforcement as a social norm indicate the cutting of green branches is taboo within the community and comes with the threat of social ostracization if broken (Lade et al., 2013). The power of taboos to promote the harvest of wild species has been noted in traditional societies worldwide (Colding & Folke, 2001), especially when coupled with small scale comanagement (Jones et al., 2008).

Illegal timber harvesting was noted by only 2% of the households surveyed, indicating that laws banning timber harvest may be widely respected. Large fines for illegal timber harvesting were identified as motivation for compliance by a high proportion of respondents. Together with this effective disincentive, we found the demand for timber to

be sated by high domestic production of predominately *Populus* spp., as in temperate regions globally (Ball et al., 2005).

There were high levels of livestock ownership within the Reserve, consistent with previous reports (Squires & Safarov, 2013). The total area available for grazing in the forest has declined as a result of land privatization (U. Gulamadshoev, pers. comm., 2017), and the quality of grazing in both forest and pasturelands has declined, indicating unsustainable use. This is reinforced by two findings: most households admitted to grazing livestock illegally in the forest, and machine learning identified low trampling as a strong influence on both species richness and Shannon's index. Illegal grazing demonstrates a disregard for grazing laws, which we believe to be systemic throughout the community, resulting from family ties between those protecting the forest and those grazing the livestock. This is compounded by the cooperative grazing management system in which a guard could have to impose a fine on somebody grazing a herd that includes the guard's livestock.

The greater species diversity and total basal area at increased distances from human settlements indicate that anthropogenic disturbance has a negative impact on this ecosystem, suggesting that continued unsustainable resource use will lead to further environmental degradation. The strong positive relationship of total basal area and the negative relationships of both measures of diversity with dung count may indicate that dung provides nutrients that enhance the growth of disturbance tolerant species, and that grazing, for which dung count is a proxy, causes a decline in species diversity. The dominance of *P. sogdiana* suggests it may be a pioneer species, as reported by Vera (2000), thriving in the disturbed landscape despite being preferentially harvested for firewood. With its rapid growth rates in high light conditions, the dominance of *P. sogdiana* may be maintained by high levels of disturbance suppressing less tolerant species (sensu Bongers et al., 2009). The high recruitment rate of *P. sogdiana* despite significant disturbance may confer resilience to the functioning of this ecosystem (Grime, 1998).

Our data provides a baseline in a chronosequence for the analysis of temporal trends in disturbance and biodiversity (Newton & Echeverría, 2014). Future work could employ Rapid Rural Assessment (Chambers, 1992) to cover a greater percentage of households than in our study, to provide deeper insight into the sustainability and social heterogeneity (Waylen et al., 2013) of NTFP use and livestock management.

Tajikistan suffers from lack of an effective legal framework, with unregulated transhumance and high levels of forest grazing being particularly damaging to forest health (Mislimshoeva et al., 2016). These factors, combined with unsustainable NTFP extraction, present significant challenges for the Forestry Department. Certain positive aspects of current government-led managerial practices could be

applied to improve the regulation of local forest use, to increase the sustainability of the system. For example, a fine coupled with an enforcement scheme reinforced by social norms, as is used to control the harvesting of green branches and timber, could be initiated to decrease the prevalence of livestock grazing in the forest. The management successes to date have been, in part, a result of well-defined laws reinforced by cultural taboos with respect to resource extraction and significant autonomy to enact and enforce these laws. Other factors positively influencing management, as detailed by Ostrom (1999), are the relatively small sizes and homogeneity of communities, who trust the local authority to deliver appropriate management and restoration. Our findings will augment stakeholder engagement strategies in Dashtijum Nature Reserve and other protected areas within Tajikistan and, specifically, will continue to inform reforestation site selection for 400,000 native trees, to enhance forest diversity and resilience to climate change (D. Gill, Fauna & Flora International, pers. comm., 2020; Darwin Initiative, 2017).

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Author contributions Study conception, design: FP, CC, VW; fieldwork: FP; data analysis: FP, MS; writing: all authors; revisions: FP, MS, CC.

Conflicts of interest None.

Ethical standards Prior to fieldwork, an ethical assessment was conducted and clearance was granted by Imperial College London (2017-01288869-PILKINGTON-FABP), and this research otherwise abided by the *Oryx* guidelines on ethical standards.

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